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Assessment of Pacific Cod off the West Coast of Vancouver Island and in Hecate Strait, November 2001

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Abstract

The Pacific cod stocks off the west coast of Vancouver Island (3CD) and in Hecate Strait (5CDE) were assessed using the available commercial fisheries research survey data. A delay-difference stock productions analysis was used to synthesize these data. For the 3CD stock, indicators of biomass and recruitment are currently very low, but have been increasing slightly in recent years. Fishing mortality and fishing effort on the stock have been reduced and this should aid stock recovery. The current Total Allowable Catch (TAC) plus carry over is 893 t. Catches in this range in 2002 would result in a decline in stock biomass and further compromise stock rebuilding. However, the TAC for this stock has never been caught. If catches continue to be similar to those in recent years, i.e. less than 200 t, there may be improvement in stock biomass.

An index of sea level height in Prince Rupert was incorporated in the assessment model for the area 5CD stock. High sea levels during January-March have been associated with high transport through the Hecate Strait area and reduced recruitment for the stock. Conditions have been unfavorable for recruitment through most of the 1990s, however, sea levels have declined in the past 2 years and recruitment may be improving. Stock biomass is estimated to be very low. Fishing mortality and fishing effort had been relatively high prior to 2001, however these were reduced in 2001 due to the reduced TAC, and this should aid stock recovery. If the current TAC of 200 t is maintained for 2002, the stock biomass may increase by between 25-35% and allow some stock rebuilding.

Résumé

Nous utilisons les données de relevés de recherche disponibles sur les pêches commerciales, mises en rapport à l'aide d'une analyse de production à retardement des stocks, pour évaluer les stocks de morue du Pacifique de la côte ouest de l'île de Vancouver (3CD) et du détroit d'Hécate (5CDE). Dans le cas du stock de 3CD, les indicateurs de la biomasse et du recrutement sont actuellement très faibles, bien qu'ils aient légèrement augmenté au cours des dernières années. La mortalité par pêche et l'effort de pêche exercé sur le stock ayant diminué, le stock devrait se rétablir. L'ensemble du TAC actuel et du report de quota se chiffre à 893 t. Des prises de cet ordre en 2002 résulterait en un déclin de la biomasse et compromettrait davantage le rétablissement du stock. Par contre, le TAC fixé pour ce stock n'a jamais été récolté. Si les prises restent aux mêmes niveaux que par les années passées, c'est-à-dire qu'elles se chiffrent à moins de 200 t, la biomasse augmentera peut-être.

Nous avons inclus un indice du niveau de la mer à Prince Rupert dans le modèle d'évaluation du stock de 5CD. Un niveau de la mer élevé de janvier à mars signifie que l'espèce transite rapidement à travers le détroit d'Hécate et que le recrutement au stock est réduit. Les conditions n'ont pas été favorables au recrutement pendant la plupart des années 1990, mais comme le niveau de la mer a diminué au cours des deux dernières années, le recrutement s'améliorera peut-être. La biomasse estimée du stock est très faible. La mortalité par pêche et l'effort de pêche étaient relativement élevés avant 2001, mais comme ils ont diminué cette année-là en raison d'une réduction du TAC, le stock devrait se rétablir. Si le TAC actuel de 200 t reste inchangé en 2002, la biomasse du stock augmentera peut-être de 25 à 35 %, ce qui permettra au stock de se rétablir dans une certaine mesure.

1. Introduction

Pacific cod (*Gadus macrocephalus*) are harvested in relatively shallow waters (< 150 m) all along the BC coast. Coastwide landings peaked in the mid-1960s at close to 15,000 t, again in the mid-1970s at just over 12,000 t and again in the late 1980s and early 1990s. Landings have been highly variable and have tended to follow changes in recruitment. Landings declined in the 1990s and have been below the long term average of 6,400 t since 1994 with landings from 1996-2000 being the lowest on record (Fig. 1, Table 1).

Four stocks of Pacific cod are defined for management purposes on the BC coast, Strait of Georgia (4B), west coast Vancouver Island (3AB), Queen Charlotte Sound (5AB), and Hecate Strait (5CDE). The species is fished almost exclusively with trawl gear. The most recent assessment of the Hecate Strait stock is given by Sinclair (2000), for the west coast Vancouver Island stock by Haist and Fournier (1995), and for the Strait of Georgia by Westrheim and Foucher (1987). No assessments have been made of the Queen Charlotte Sound stock.

This Research Document will focus on the west coast Vancouver Island and Hecate Strait stocks. The objective is to address the questions asked in the "Request For Working Paper" given in Appendix I. Specific objectives are:

1. To review surveys, biological, sampling, catch records, logbooks, observer reports, and fishing practices for Pacific Cod to provide a basis for management for the 2002/2003 fishery in Hecate Strait and west coast Vancouver Island;
2. To provide an assessment of Hecate Strait and west coast Vancouver Island pacific cod stock status;
3. To provide stock projections based on various yield options;
4. To recommend appropriate yield options;
5. To recommend a stock monitoring program for Hecate Strait pacific cod.

The Research Document is divided in 2 main sections, one for each stock. Stock status indicators are reviewed and summarized in a "Report Card" format. A delay-difference stock production model is used for each stock. An environmental covariate is introduced in the Hecate Strait model and the consequences of environmental variation on biological reference points and stock projections are investigated.

2. Methods

2.1 Data Sources

2.1.1 Fishery data

Catch and effort data from the Canadian groundfish trawl fishery were obtained from 2 sources. The GFCATCH database (Rutherford 1999) contains landing slip, interview, and logbook information for fisheries between 1954-1995. These 2 sources of information were combined to form "fishing event" records. From 1954-1990, these events were aggregations of individual fishing sets where the aggregation was done by

fishing locality and depth zone within individual fishing trips. Fishing events consisted of individual fishing sets between 1991-1995. For 1994 and 1995, fishing locations were recorded by latitude and longitude instead of larger fishing localities. The PacHarvTrawl database (1996 to present) consists of set-by-set data collected by either fisheries observers (the vast majority) or captured from logbooks, and trip landings data collected through dockside monitoring. These data are combined in such a way that the landings data, considered to be the most accurate data on total catch, are prorated according to the set-by-set catch estimates. Non-Canadian total annual catch data were taken from previous assessments of the stocks. These catches occurred between 1954-1978 and they were inferred by subtraction of the Canadian annual catch from the total catches provided in Haist and Fournier (1998). The catch and effort data were used as the source for describing the spatial and seasonal distribution of the fishery and for developing a catch per unit effort abundance index for the stocks.

Historical size composition data for the commercial catches of Pacific cod were obtained from V. Haist, the lead author of previous assessments of these stocks. For the west coast Vancouver Island stock, this included data from 1956-1995. For the Hecate Strait stock, this included the years 1956-1998. The time series were brought up to date using sample data from recent years. The samples were obtained either in port by DFO port samplers or at sea by fisheries observers. Samples were combined by quarter after weighting individual samples by the ratio of catch divided by sample weight. For sea samples, the catch weight was the weight of the individual fishing set catch from which the sample was drawn. For port samples, the catch weight was the weight of the landing.

2.1.2 Hecate Strait groundfish survey

A trawl survey of the Hecate Strait area was conducted on the CCG vessel W.E. Ricker in May-June, 2001. The objective of the survey was to collect biological data on commercial groundfish stocks in the area as well as to collect other data for hydrographic and geological purposes. In addition, several fishing sets were allocated to areas designated as being good places to find Pacific cod. The designation was done by knowledgeable fishermen from the Prince Rupert area. This survey was not an extension of the Hecate Strait groundfish assemblage survey time series, results of which are given in Sinclair 2000. Nevertheless, some qualitative comparison of results in terms of catch rate and size composition were made.

2.1.3 Shrimp survey index

A shrimp trawl survey has been conducted off the west coast of Vancouver Island beginning in 1973. The spatial coverage of the survey varied among years. The greatest coverage was in Pacific Fisheries Management Area (PFMA) 124 (Fig. 2) which was sampled annually with the exception of 1974, 1984, and 1986. PFMA 125 was not sampled in 1974, 1984, 1986, 1989 and 1991. PFMA 123 was sampled in 1996-2001. PFMA 23, which is inshore in Barkley Sound, was surveyed with a net equipped with a fish exclusion device and thus the results were of little interest as an index of fish biomass. The weights of Pacific cod catches were recorded throughout the time series.

The survey followed a systematic design with stations located along Loran lines, e.g. Y lines, 20 microseconds apart; and Z lines, 10 microseconds apart. Inner and outer boundaries were determined by fishing this grid system until shrimp catches were negligible or the bottom became too rough to trawl. Steps were taken to maintain sampling gear and fishing effort comparable between surveys. However, changes in gear were unavoidable. From 1973 to 1976 the survey was conducted using a semi-balloon trawl with wood flat doors, and fitted with a bobbin and roller groundline (Butler et al. 1973). In 1976 the trawl was changed to a National Marine Fisheries Service (NMFS) high-rising shrimp sampling trawl fished with steel Vee Doors (Boutillier et al. 1976). During the 1976 survey, comparative tows between the high rise and the semi-balloon trawl were made and the NMFS trawl was found to be 1.4 times more efficient in catching shrimp per unit area swept (Boutillier et al. 1976). Because the efficiency of the nets have not been calculated for catching efficiency of fish species such as cod, the historical data have **NOT** been adjusted to reflect the use of the NMFS trawl as the standard sampling gear. This would if anything tend to bias the indices for fish species towards under-estimates for 1973 and 1975. The gear may have changed over-time due to repairs, stretching etc., there is no information at the present time to determine how this would effect the standardized effort. However, over the last 10 years a net sonar on the headline of the trawl has been used to monitor trawl dimensions and performance during almost every tow. Any substantial changes in the trawl opening dimensions are readily picked up and appropriate actions and adjustments can be readily made.

Most of the offshore surveys (121, 123, 124, and 125) have been conducted using the research vessels G.B.Reed (1973-1985) and W.E.Ricker (1987-present). Exceptions to this were a multiple vessel survey in the fall of 1977 aboard the F.V. Gypsy Traveller, Deliverance, Pacific Trident and Crino D'Oro, a fall survey in 1978 aboard the F.V. Ocean King and a spring survey in 1989 aboard the F.V. Sharlene K. Differences in fishing power that may have occurred because of differences in vessel power, warp size, etc. have not been measured or adjusted for in any way.

All tows were of 30 minutes duration, unless shortened due to snags, etc. The distance traveled was calculated using the technology of the day. In the early years, this was start and stop loran locations while today a much more accurate differential global positioning systems (DGPS) is used. This has resulted in a trend towards a shorter distance traveled for a 30 minute tow over the years. At this time no attempt has been made to account for the errors or differences between the surveys to reflect this increase in accuracy of distance towed. Surveys were always conducted during daylight hours to reduce the problems associated with the known diurnal vertical migration of some shrimp species at night.

The density of cod by weight per square meter was calculated for all tows. This data along with the latitude and longitude of the center point of each tow was then imported into Arc View GIS system. The cod biomass indices were modeled for the offshore areas in question by interpolating the distribution from the sample tow density using an inverse distance weighted interpolation procedure. The total area of fishable shrimp grounds for each survey area was masked off and the area was divided into 300 x 300 meter (90,000 m^2) grids. The center point of a tow was assigned to the appropriate grid cell along with the weight densities. The blank grid cells were then filled in with interpolated values and

the biomass indices were then calculated by summing the values in each grid within the larger masked boundaries of each survey area. All the biomass index calculations were made within the Arc View GIS software package.

2.2 Catch per unit effort analysis

Commercial catch per unit effort indices were calculated for each stock in the following manner. The depth range where Pacific cod are commonly found in each area was determined and data from outside this range were eliminated from the analysis. There have been important changes in the depth distribution of fishing effort in each stock area, with an expansion of the fishing grounds toward deeper depths in more recent years. Pacific cod tend to be found in relatively shallow water, therefore including data from deeper zones in more recent years would bias the catch per unit effort series downward. There have also been a number of fishery closures over the years based on area and season. These closures were considered when selecting data for analyses. The measurement of the central tendency of the data was also considered. In previous assessments, the median of the non-zero event-specific catch per unit effort was used. Two factors weigh against this approach. First, this approach eliminates all non-zero catches from the index. Second, the more recent observer data tends to contain more small catches of individual species than the earlier logbook data. This is the likely consequence of fishing captains not recording small by-catches in their logbooks. As an alternative, I used an effort weighted mean catch per unit effort, i.e. the ratio of the sum of catch divided by the sum of effort. Specific details on the areas and seasons used in each stock index are given in the respective results sections.

2.3 Swept area biomass index

Catch per unit effort is a density measure. When catch per unit effort is treated as a biomass index, an assumption is made that the area over which this density is measured remains constant from year to year. An alternative approach is to calculate both the density and the area fished. The product of density and area would be a more accurate index of biomass, provided the total area occupied by the stock is sampled (Beverton and Holt 1957). This is the basis of swept area measures of fish abundance and biomass (Walters and Bonfil 1999, Schnute and Haigh 2000, Sinclair 2000). The availability of precise fishing location data from logbooks (1994-95) and observers (1996-2000) allows such calculations to be done.

The approach taken here was to divide the stock area into a rectangular grid of 0.05 degrees latitude and longitude. The effort weighted mean catch per unit effort in each rectangle was calculated and assumed to represent the mean fish density in the grid. The fish biomass index for the area was then calculated as the sum of the densities in each rectangle. The stock area was calculated as the number of rectangles that contained the upper 95% of the biomass index.

2.4 Delay-difference production analysis

A delay-difference stock production model (Hilborn and Walters 1992) was used to estimate stock parameters relevant to management. The model uses 2 age groups,

recruits and spawners. A stochastic Ricker stock-recruitment function was used to link the 2 groups. Recruitment to the spawning population and the fishery was assumed to be knife edged at age 2. Growth was assumed to follow a constant von Bertalanffy function and the length-weight relationship was assumed constant. Input parameters for growth were obtained from Westrheim (1996). The model is conditioned on fishing effort, estimated as the ratio of catch divided by catch per unit effort. The objective function includes terms for predicted vs. observed catch, predicted vs. observed mean weight of individuals, and recruitment anomalies. A non-equilibrium surplus production model was used in the previous assessment of the 5CD Pacific cod stock (Sinclair 2000). The delay-difference model used in the current assessment was considered to be an improvement because it allowed for a stochastic stock-recruitment relationship.

An environmental covariate was included in the stock/recruitment relationship for the Hecate Strait stock. Fournier (1983) reported a negative effect of sea level height on Pacific cod recruitment success in Hecate Strait. Tyler and Crawford (1991) tested several possible environmental stock recruitment functions for this stock including circulation, temperature, herring as prey for young cod, and herring as prey for spawners. They concluded that the circulation hypothesis was the most effective in explaining recruitment anomalies for the stock. Sea level at Prince Rupert during the spawning period (January-March) was used as an index of circulation. High sea levels indicated high circulation through Hecate Strait and this resulted in low recruitment success. The hypothesis being that eggs and larvae were removed from the area by strong currents. Based on these analyses, the effect of sea level on stock production model was introduced as an effect on the slope at the origin of the stock recruitment curve. Sea level data were available since 1962 with the exception of 1986. The sea level was assumed to be average in years when data were missing. The data were transformed into standard deviates from the overall mean.

The model formulation was as follows.

Estimated Parameters

B_0 - unfished population biomass

γ - ratio B_1 / B_0, population size in year 1 relative to unfished population size

δ - steepness of stock-recruitment curve, multiplier between slope at unfished equilibrium and at the origin of the stock recruitment curve

q - fishery catchability

ϕ_t - recruitment anomolies in year t

M - natural mortality rate

τ - sea level effect on recruitment

Input parameters from other sources

L_∞ = 89.48 - maximum length in von Bertalanffy growth equation

k = 0.307 - growth rate parameter in von Bertalanffy growth equation

t_0 = -0.116 - time at L=0 in von Bertalanffy growth equation

a = 7.38E-06 - slope of length – weight relationship (kg)

b = 3.0963 - exponent of length – weight relationship

r = 2 - age of knife edge recruitment to fishery and spawning population

Annual Input Data

E_t - fishing effort in year t

P_t - sea level at Prince Rupert in year t

C_t - weight of catch in year t

w_t - mean weight of individuals in the population in year t

Parameters Derived From Leading Parameters

$\rho = 0.836$	slope of the Ford-Walford plot, age 2-20
$\alpha = 1.41$	intercept of Ford-Walford plot, age 2-20
$w_r = a(L_\infty(1-e^{-k(r-t_0)}))^b$	weight at the age of recruitment
$S = e^{-M}$	natural survival rate
$\overline{w} = \frac{(S\alpha + w_r(1-S))}{1-\rho S}$	average body weight in the unfished population
$N_0 = \frac{B_0}{\overline{w}}$	unfished equilibrium population numbers
$R_0 = N_0(1-S)$	unfished equilibrium recruitment
$s_0 = \frac{\delta R_0}{B_0}$	maximum recruitment survival, slope at the origin of stock recruitment curve
$\beta = \frac{-\ln(1/\delta)}{B_0}$	recruitment capacity

Model Equations

$F_t = qE_t$	instantaneous fishing mortality in year t
$N_t = N_{t-1}e^{(-M-F)} + R_{t-r}$	population numbers in year t
$B_t = (\alpha N_{t-1} + \rho B_{t-1})e^{(-M-F)} + w_r R_{t-2}$	population biomass in year t
$\hat{w}_t = \frac{B_t}{N_t}$	predicted mean weight of individuals in the population in year t
$R_t = s_0 B_t e^{(-\beta B_t)} e^{(\tau P_t)} e^{(\phi_t)}$	recruitment in year t
$\hat{C}_t = \frac{B_t(1-e^{(-M-F)})F}{M+F}$	predicted catch in year t

Objective Function: minimize

$$n\ln\sigma_\phi + \frac{1}{2\sigma_\phi^2}\sum(\phi^2) + n\ln\sigma_C + \frac{1}{2\sigma_C^2}\sum(\ln C_t - \ln\hat{C}_t)^2 + n\ln\sigma_w + \frac{1}{2\sigma_w^2}\sum(\ln w_t - \ln\hat{w}_t)^2$$

The residual standard deviations for weighting the three components of the objective function were arbitrarily set to $\sigma_\phi = 0.4$, $\sigma_w = 0.2$, and $\sigma_C = 0.2$ for the recruitment anomalies, mean weights, and catch respectively. It was reasoned that the recruitment process error should have the highest variability of the three. The variation in mean weight at age may reflect, to a large extent, observations error while the variation around predicted catch would reflect mainly process error in catchability.

Equilibrium Predictions

$S_e = e^{-M-F}$ survival rate with fishing

$w_e = \frac{S_e\alpha + w_r(1-S_e)}{1-\rho S_e}$ average weight

$B_e = -\ln\left(\frac{(w_e - S_e\alpha - S_e\rho w_e)}{w_r s_0 w_e}\right)/\beta$ population biomass

$N_e = \frac{B_e}{w_e}$ population numbers

$Y_e = \frac{B_e(1-e^{(-M-F)})F}{M+F}$ yield

The model parameters were estimated using the Solver Add-in in Microsoft Excel '97.

2.5 Report card

Information from various sources for each stock are summarized in a Report Card similar to that discussed in Richards and Schnute (2000). The report card is presented as a summary of information and interpretation and is not meant to replace yield forecasts and prognoses derived from the assessment model. The indicators are separated into primary and secondary ratings. Among the primary ratings are indicators of biomass, recruitment, recruits per spawner, mortality, fishery, production, and industry input. These indicators may be interpreted directly in terms of stock status. Among the secondary indicators are size structure, maturity, growth, spatial distribution, predators, prey abundance, and oceanography. The interpretation of these indicators may be ambiguous or there may be so little information available that no interpretation is possible. For example, if the size composition is dominated by small fish, this could mean either good recruitment or a lack of large fish. Such indicators need to be interpreted in relation with others. The knowledge status of each indicator is evaluated with respect to the amount of data available, it's reliability, and relevance. The individual observations are described, interpreted, and comments on uncertainties are included where appropriate. Then, each indicator is ranked in 4 categories in terms of stock status, danger (among the lowest observed), low (below target but above danger), neutral (close to target or ambiguous), healthy (above target or beneficial to stock production).

3. Area 3CD, West Coast Vancouver Island

3.1 Description of the Fishery

Pacific cod are taken as part of the mixed-species groundfish trawl fishery off the west coast of Vancouver Island. Pacific cod ranked among the top 4 species in volume landed from the 3CD management areas in each decade from the 1950s to the 1990s. However, this ranking dropped to 17th in 2000-2001. Detailed interview and logbook data describing fishing locations and catch composition of Canadian vessels participating in this fishery are available since 1954. The trawl fishery was initially concentrated in the 0-199 m (0–109 fm) depth zone where almost all of the fishing effort was exerted until the early 1980s (Fig. 3). Total fishing effort varied between a low of 2300 hr in 1958 and a high of 8300 hr in 1972. The fishery expanded into the 200-699 m (109-384 fm) depth zone in the mid to late 1980s. The precise timing of this transition is unclear because a large amount of fishing effort was reported from unknown depths during this period. This uncertainty was reduced in 1992 when the proportion of total effort reported from unknown depths was greatly reduced. Fishing effort in 3CD was split almost equally between the 0-199 m and 200-699 m depth zones in 1992. Total fishing effort increased by a factor of 4 between 1987 and 1992 when it reached an all time high of 22,500 hr in the area. Fishing effort expanded into the >=700 m (>= 384 fm) depth zone in the mid-1990s. This was accompanied by a decline in effort in the 2 shallow depth intervals.

Most of the Pacific cod landings come from the 0-199 m depth zone. Between 1954-1995, over 95% of the reported landings that could be attributed to a depth zone were reported from 0-199 m. This declined to roughly 85% between 1996-1999, but increased to over 90% in 2000 and the first half of 2001.

Canadian landings data for Pacific cod were obtained from the GFCatch (1954-1995) and PacHarvTrawl (1996-2001) databases. Total landings data, including USA and foreign catches prior to the extension of jurisdiction, were obtained from Haist and Fournier 1998 (Table 1). Canadian and total landings are compared in Fig. 4. The fishery became exclusively Canadian in 1979.

Total landings of Pacific cod were highly variable. The historic maximum occurred in 1972 at 5600 t. Other peaks occurred in 1966, 1989, and 1992. Landings declined considerably between 1993 and 1996, and have remained below previously reported lows ever since.

Annual TACs for Pacific cod were introduced in this area in 1994. These were managed on a calendar year basis until 1996. Beginning with the 1997-98 period, the fishing year was changed to April 1 to March 31. None of the TACs were attained (Table 2). Provisions exist in the Groundfish Trawl Management Plan to carryover up to 37.5% of the uncaught portion of individual vessel quotas (IVQ) to the following year. Since the TACs were never caught, this resulted in carryovers of 205 t and 200 t in the 2000/01 and 2001/02 fishing years respectively. In 1994, 56% of the TAC was taken, in 1995 50% was taken. Since then, less than 20% of the annual TACs plus carryover were taken. A voluntary increase in mesh size was suggested for this fishery in 1991 and was then regulated in 1995.

The majority of landings have been made in the first half of the year. For several years, more than 50% of the annual landings came from the first quarter of the year, the spawning period, and from spawning grounds on Amphitrite Bank. Concern about the possible harmful effects of an intensive fishery during the spawning season led to the implementation of spawning closures of various duration in the first quarter of the year between 1978-1983 and 1985-1988 (Tyler and Foucher 1990). In general, landings from the spawning grounds during spawning were lower in years in which these closures were in effect. The closures were lifted in 1989 and the highest spawning season landings were recorded thereafter. Concern over the status of the stock and the potential effect of intensive fishing during spawning led to a reinstitution of the spawning closure in 1999.

The majority of landings off the west coast of Vancouver Island came from management area 3C. In general, over 80% of the annual landings were from 3C. This declined to around 70% in the late 1960s and again in the mid-1990s. Within area 3C, the landings came from the Swiftsure, Amphitrite, and Big Banks (Fig. 2).

3.2 Commercial Catch per Unit Effort

The commercial catch per unit effort index was calculated in a manner similar to previous assessments. Only data from April-December were included in the index. Most previous assessments have restricted the catch per unit effort data to these months to avoid potential bias caused by the numerous spawning closures in the area (Stocker et al. 1995). As has been the practice in all previous assessments, data from 3C only were included in the index. The index was also restricted to fishing events from the 0-199 m depth zone. This was because of the large increase in fishing effort in deeper depth zones where Pacific cod have not been found in any abundance in previous years. The index was calculated as an effort weighted mean of all observations, i.e. the sum of catch divided by the sum of effort. The new catch per unit effort series was highly correlated with the previous series presented by Haist and Fournier (1995) ($r=0.90$).

The catch per unit effort series had several peak periods, in the mid-1960s, the early 1970s, the late 1970s, and the late 1980s (Fig. 5). The series declined in the early 1990s and reached an historic low in 1998. Since then, there has been an increase to 2001. The most recent value is less than half the long-term average.

3.3 Swept Area Biomass Index

A "swept area" biomass index was calculated from the set-by-set commercial data available since 1994. Data from area 3C between April-December were used. No attempt was made to correct for the width of the trawl or the catchability of the gear. Therefore, this is an index of biomass rather than an absolute estimate. The biomass index showed a very similar trend to the catch per unit effort index, declining from 1994 to 1998 and increased thereafter (Fig. 5). There was a decline of approximately 25% of the stock area between 1994 and 2000.

3.4 Commercial Catch Size Composition

Sampling levels for the stock have varied considerably over the years (Table 3). An average of close to 5000 fish were measured annually between 1956 and 1979. This declined to less than 1000 measurements annually between 1980 and 2000. Sampling was particularly low when there was an average of 300 fish measured per year and there was no sampling in 1997. Sampling increased considerably in the second quarter of 2001 when over 2000 fish were measured.

The size composition of commercial landings from recent years were examined for evidence of improved recruitment. In earlier years, when a large year-class appeared in the population, it was possible to follow a strong mode in the length frequency distribution for a number of years. An example is for the period 1988-1990 when the large 1985 year-class recruited to the population (Fig. 6). The mode in the distributions moved from 55 cm range in 1988 to 71 cm in 1990. The length frequencies for 1999-2001 are presented for comparison. In these length frequencies, the modes were 47 cm in 1999, 69 cm in 2000, and 47 cm in 2001. This qualitative comparison of length frequency data does not indicate that there has been a significant recruitment event in this stock during the period 1998-2000. However, the low sampling levels in 1999 and 2000 may mean that the size compositions were not well estimated making the detection of a change difficult.

Trend in mean weight of fish in the catch was quite variable and this may also reflect the low sampling levels (Fig. 7). The mean weights in 1994,1996, 1998, 1999, and 2001 were among the lowest observed since 1956.

3.5 Shrimp Survey Index

The cod biomass index from the shrimp surveys off the west coast of Vancouver Island indicate a general agreement with the commercial catch per unit effort index (Fig. 8). A combined index was made by summing the indices for areas 124 and 125 in the years in which both were surveyed. The shrimp survey combined index increased sharply in the late 1980s, declined rapidly in the early 1990s, then had moderate increases in the late 1990s until 2001. This trend was similar to that in the commercial catch per unit effort series. There was poorer agreement between the shrimp survey and commercial index in the early years of the survey (1973-1980). Area 123 was only surveyed since 1996. It also indicated an increase in biomass in the most recent years.

3.6 Analysis

3.6.1 Delay Difference Production Analysis

Input observations and model predictions for the production analysis are given in Table 4 and key parameter estimates are given in Table 5. The catch time series had a high dynamic range and the model fit to the time series was reasonable (Fig. 9). The catch residuals had a relatively low serial correlation (r=0.33, lag=1). There was lower dynamic range in the mean weight time series and the model fit to this series was weaker than to the catch time series. The main contribution of the mean weight data to the model was to improve the estimate of the natural mortality rate. The recruitment anomalies had

high serial correlation (r=0.73, lag=1) as is often seen for recruitment time series. Of note are the series of negative anomalies in 1991-1994.

The initial predicted stock biomass was 12,773 t. There were 3 main peaks in biomass, in 1965 (17,000 t), 1972 (25,000 t) and 1989 (12,000 t) (Fig. 10). Biomass declined following the third peak and reached an historical minimum of 2,123 t 1996. The predicted biomass increased somewhat thereafter, reaching 4,511 t in 2001, but this remains below previous minima in the 1980s and 1960s. The peaks in biomass were all preceded by peaks in recruitment. Predicted F varied between 0.1-0.4 from 1956-1990 then increased sharply to between 0.7-0.9 from 1991-1995. This period of high fishing mortality corresponded with a series of low recruitment anomalies. In combination, this resulted in very low stock biomass and recruitment in recent years.

A retrospective analysis of model estimates was done to investigate the influence of the most recent catch per unit effort data on the solution. The model was calibrated using data up to and including 1995. Stock biomass was predicted forward to 2001 using the observed catches. Two projections were done. One set the recruitment anomalies to 0. The second used the recruitment anomalies estimated in the analysis that included all years. The key parameter estimates are given in Table 5. There was little difference in parameter estimates. The main difference was that the initial biomass, natural mortality, and productivity (s_0) were higher in the retrospective analysis. There was a greater increase in biomass in the most recent years in the retrospective analysis than in the analysis using the entire catch per unit effort time series (Fig. 11). There was little difference between the biomass projections with and without recruitment anomalies. Thus, the higher projected biomass from the retrospective analysis was likely the result of a higher productivity estimate.

The results of the production analysis were compared with those from the last analytical assessment of this stock (Haist and Fournier 1995) (Fig. 11). The trends in biomass were highly correlated (r=0.93) and the estimates were of similar scale.

An advantage of the production model assessment is that biological reference points such as stock biomass associated with maximum sustainable yield (B_{msy}), the fishing mortality associated with maximum sustainable yield (F_{msy}), and the unsustainable fishing mortality (F_{crash}) are outputs of the model. Sinclair (2000) discussed a management framework that included various zones of stock biomass and fishing mortality. A target zone was where stock biomass was above B_{msy} and fishing mortality below F_{msy}. Overfishing would occur if fishing mortality exceeded F_{msy}. The stock would be overfished if biomass was below B_{msy}. It would be undesirable and potentially dangerous to the stock if biomass was less than $0.5\,B_{msy}$ or fishing mortality was above F_{crash}. This approach is similar to a framework for implementing the precautionary approach to fisheries management proposed in Richards and Schnute (2000).

Where has the stock been relative to these biological references points? The model predictions indicate that for much of the time series (1956-1990) the fishing mortality

was above F_{msy} and the biomass above 0.5 B_{msy} (Fig. 12). In 8 years the biomass was above B_{msy}. Fluctuations in biomass during this period were largely due to variation in the recruitment anomaly. Fishing mortality increased considerably in 1991 to values not seen before and the stock biomass declined sharply. There has been little increase in biomass in recent years despite a large reduction in fishing mortality. The point estimate of biomass in 2000 is approximately 25% of B_{msy}.

3.6.2 Report Card

Information from the various sources presented above are summarized and interpreted in a Report Card format in Table 6. Indicators of biomass were in the danger and low categories. Recruitment has also been in the danger category for several years. While recent recruitment anomalies have been average, spawning biomass is very low leaving little production for stock recovery. Fishing mortality and fishing effort on the stock have been reduced in recent years and this should aid stock recovery. Cod are taken largely as by-catch in other fisheries. There have been some reports of increased abundance in 2001, however there have been no requests for increases in TAC to allow higher catches in other fisheries.

There are few data available on secondary indicators. The size composition of commercial catches have not indicated a large mode passing through the population. This may be due in part to a low level of sampling in recent years. There has been a small reduction in fishing area in recent years, but some fishermen have indicated that Pacific cod are being found over a larger area then in past years. Information is lacking on changes in growth, maturity and condition.

3.6.3 Current Status and Prognosis

The results of deterministic catch projections are summarised in Fig. 13. A range of 2002 catches of 0-900 t was used. The catch in 2001 was assumed to be 200 t. This was considered reasonable given the reported catch to date (Table 2). Three criteria were investigated. The first was the change in biomass between the beginning and end of 2002. With no catch in 2002, stock biomass is predicted to increase by 18%. A catch of approximately 180 t would allow a 10% increase in biomass while a catch of 390 t would result in no change in biomass. A catch of 600 t would result in a 10% decline in biomass and a catch of 900 t would cause a 25% decline in biomass. The second criterion was to compare the 2002 fishing mortality to F_{msy}. A catch of 250 t would result in F_{msy} while a catch of 480 t would generate a fishing mortality approximately 2.0 F_{msy}. The third criterion was how close the surviving biomass would be to B_{msy}. With no catch in 2002, the surviving biomass would be approximately 25% of B_{msy} and a catch of 900 t would leave a biomass of 14% B_{msy}.

Current stock biomass is well below the B_{msy} target and recruitment is low. The current TAC plus carry over is 894 t. Catches in this range in 2002 would result in a decline in stock biomass and further compromise stock rebuilding. The TAC for this

stock has never been caught. If catches continue to be similar to those in recent years, i.e. less than 200 t, there may be improvement in stock biomass.

3.6.4 Uncertainties

The analytical portion of the assessment is based largely on the commercial catch per unit effort time series. There may be several problems with such indices given recent changes in fishing strategies and management practices. However, the trend in Pacific cod biomass indicated by the fishery independent shrimp survey on the west coast of Vancouver Island supports the commercial index. This increases our confidence in the overall assessment results.

The production analysis presented here could benefit from further investigation. Time constraints precluded investigation of the statistical properties of the various estimates. This additional work could be undertaken in the near future. Of particular interest would be the robustness of the biological reference point estimates. Of all the model outputs, these may be the most uncertain. Various trial runs indicated the trends in biomass and fishing mortality were fairly robust, but the biological reference points, which depend largely on estimates of M and s_0, were quite variable. Thus, one should use these with caution.

4. Area 5CD, Hecate Strait

4.1 Description of the Fishery

Annual landings of Pacific cod show considerable variability (Fig. 14). There were major peaks in landings in the mid-1960s (9519 t in 1966), the mid-1970s (5036 t in 1975), in 1987 (8870 t) and 1991 (7655 t). The minimum annual landing was recorded in 2000 (504 t), and landings since 1994 have been among the lowest on record.

Annual total allowable catches (TACs) were introduced in the Hecate Strait area in 1992. These were managed on a calendar year basis until 1996. Beginning with the 1997-98 period, the fishing year was changed to April 1 to March 31. The original TAC was 3,400 t and landings exceeded this figure by about 50% (Table 7). The TAC was increased to 5,100 t in 1993, and then reduced in steps to 1000 t in 1998/99. The low catch in relation to the TAC in 1999/00 led to a carryover of 283 t in 2000/01. With the exception of 1992, the landings have been below the TAC plus carryover with between 39% (2000) and 85% (1998/1999) being landed. The TAC was reduced to 200 t in 2001/02 due to very low stock biomass. No carryovers were allowed. So far in the current fishing year, 31% of the 200 t TAC has been landed (as of Oct. 15). A voluntary increase in mesh size was suggested for this fishery in 1991 and was then regulated in 1995.

The groundfish trawl fishery in area 5CD occurs from Dixon Entrance in the north, through Hecate Strait and into Moresby Gully in the south (Fig. 15). A large number of species are exploited and each is distributed widely throughout the area. Pacific cod ranked second in total catch during 1996-2001 in this multispecies groundfish fishery. Other species in the top 6 were arrowtooth flounder, rock sole, walleye pollock, English

sole, and Dover sole respectively. Cod density, measured by commercial catch per unit effort, is highest over the Two Peaks, Butterworth, White Rocks, Bonilla, and Horseshoe fishing grounds (Fig. 16).

A substantial quota reduction was implemented for Pacific cod in area 5CD in the fishing year 2001-2002, from 1283 t to 200 t. This reduction was made because of very low stock biomass estimated in the November 2000 stock assessment (Sinclair 2000). At that time, there was a substantial portion of the 2000-2001 fishing year TAC that was not caught. In order to avoid fishing this up during the remaining months of the fishing year, an agreement was reached between DFO and the groundfish trawl fleet to close all of the above mentioned fishing grounds, with the exception of the northern edge of Two Peaks, between February 6-April 30, 2001.

The low TAC in 2001-2002 had a noticeable effect on the distribution of fishing effort. During the second quarter of 2001, there was little fishing over the sections of the Butterworth, White Rock, Bonilla, and Horseshoe grounds which had given the highest cod catch per unit effort in previous years (Fig. 16). Reports from the industry indicate that the good cod fishing grounds had to be avoided to preserve cod quota for by-catch in other fisheries.

Given the large closure in Hecate Strait during the first quarter of 2001 and the shift in fishing away from cod grounds during the second quarter, it was decided not to use catch per unit effort or swept area biomass indices from these months in any further stock analysis.

Additional analyses of seasonal depth distributions of cod catches are given in Sinclair (2000).

4.2 Input Data

4.2.1 Commercial CPUE

Pacific cod are caught at depths less than 150 m. A commercial catch per unit effort index was calculated using all trawl data for the 0-150 m depth range. An annual index was calculated as the sum of catch divided by the sum of effort. This new series is very similar to that used last year (correlation between series 0.96). Three major peaks occurred in Pacific cod density (Fig. 17), in the mid-1960s, the mid-1970s, and the late 1980s. Catch per unit effort declined since the last peak and reached an historic low value in 2000.

4.2.2 Swept Area Biomass Index

An annual swept area biomass index was calculated for Hecate Strait in a similar manner as for the west coast of Vancouver Island. Data from all months of the year were used. However, the data from 2001 were not included for reasons described above. The swept area biomass index indicated a declining trend from 1994-2000. The 2000 value was the lowest in the series.

4.2.3 Size Composition

The size composition of commercial landings of Pacific cod were examined for evidence of improved recruitment. Sample size per quarter is summarized in Table 8. Quarterly length frequencies for 1999 – 2001 were compared to those from 1987, the last time a significant year-class appeared in the stock. The 1987 length compositions showed a large abundance of small fish, with a dominant mode in the high 40 and low 50 cm length classes (Fig. 18). The 1999, 2000, and 2001 length compositions were more broadly distributed. They were bi-modal in the latter periods of each year, indicating some recruitment. However, the lower mode was never dominant in the length composition. It should be noted that the commercial mesh size used in 1987 was smaller than in 1999-2001, and this would result in a shift in the commercial length compositions to larger lengths in recent years. But, it is doubtful that this change in mesh size would result in the suppression of a length frequency mode caused by the arrival of a large year-class. This qualitative comparison of length frequency data indicates that there has not been a significant recruitment event in this stock during the period 1999-2001.

The mean weigh of fish in the catch varied between 2.0 – 2.5 kg from the mid-1950s until the late 1980s (Fig. 7). The mean weights then increased to approximately 3.0 kg in the 1990s.

4.2.4 Research Vessel Survey

Pacific cod catches in the 2001 groundfish biological survey were in general smaller than in previous years. An exceptionally large catch was made in the Horseshoe area (Fig. 19). The fishing captain spent 30 minutes scouting the area using the echo sounder searching for indications that cod were present before making the set. In a normal assemblage survey, the fishing captain does not scout an area looking for fish before setting. This one set dominated the total catch of the survey, making up 84% of the average (Fig. 20). The fish in this set were quite large, averaging 76 cm in length.

The size composition of the total survey catch showed a peak in the high 20 cm range, which were most likely 1 year old fish (Fig. 21). This peak was larger than in 1996 and 2000, comparable to that in 1991, and smaller than in other years. Consequently, the survey does not indicate that a large year-class is entering the population.

4.2.5 Sea Level at Prince Rupert

Winter (Jan.-Mar.) sea level data for Prince Rupert were supplied by W. Crawford, Institute of Oceans Science, DFO, Sidney, BC. The data are corrected for atmospheric pressure and general sea level rise. There were 3 high sea level years in the 1990s, 1992, 1993, and 1998 (Fig. 22). Sea level in 2000 was about average and the most recent value in 2001 was below average. The 5-year running mean sea level was about 0.5 standard deviations below average during the early 1970s and late 1980s. The 5-year running mean was about 0.5 standard deviations above average in the early 1980s and most of the 1990s. The implications of these variations in sea level on stock production are discussed in the following section.

4.3 Analysis

4.3.1 Delay Difference Production Analysis

Two main effects were explored with the delay difference model, the effect of sea level on recruitment and the influence of the most recent biomass index data (1995-2000) on the solution. The first effect was explored by comparing model output with and without the sea level covariate. Input observations and model predictions for these 2 production analysis are given in Table 9 and key parameter estimates are given in Table 10 and 11.

The potential effect of sea level on recruitment and stock production was investigated by comparing model estimates with and without the sea level covariate. The objective function was 7% lower when sea level was included in the model than without (Table 12). The recruitment anomaly component was 25% lower, the catch residuals 22% lower, and the mean weight residuals 3% higher with the sea level effect than without. The model without sea level had higher B_0 and lower γ estimates than the model with sea level, but the net result was similar initial biomass estimates of 6,780 t and 6183 t respectively. The model without sea level produced a lower productivity estimate, i.e. s_0, had a higher B_{msy} and lower F_{msy} estimates than the model with sea level. The estimated recruitment anomalies were negative for most of the 1990s in both models and the mean weight residuals were positive for the same time period (Fig. 23). No attempt was made to adjust for changes in mesh size used in the trawl fishery that occurred during the early 1990s. This change may explain the anomaly and residual patterns. If so, it is possible that recent recruitment estimates are biased downward.

Predicted trends in biomass and fishing mortality were very similar between the 2 models (Fig. 24). The main difference was that the model with sea level produced more variable recruitment estimates. Another important difference were the reference point estimates, illustrated in Fig. 25. In particular, the B_{msy} reference point was lower in the model with sea level, and this essentially shifted the management goal posts while not affecting the estimated stock trajectory.

The effect of variation in sea level height on production of area 5CD Pacific cod was investigated by estimating equilibrium yield curves when sea level was +- 0.5 standard deviation of the mean sea level. When sea level was 0.5 standard deviation above the mean, B_{msy} was estimated as 11,131 t, F_{msy} was estimated as 0.19, and F_{crash} was estimated as 0.48 (Fig. 26). When sea level was 0.5 standard deviation below the mean, B_{msy} was estimated as 14,911 t, F_{msy} was estimated as 0.32, and F_{crash} was estimated as 0.94. These results indicate that if sea level anomalies persist over several years, as has been observed (Fig. 22), it may be prudent to shift target fishing mortality and biomass accordingly.

A retrospective analysis of model estimates was done to investigate the influence of the most recent catch per unit effort data on the solution. The model with sea level was calibrated using data up to and including 1995. Stock biomass was forecast forward to 2001 using the observed catches and the sea level covariate. Two options were used for

the recruitment anomalies in the forecast period, either set to 0 or set to the values estimated in the full analysis .

The key parameter estimates are given in Table 12. The main difference in parameter estimates between the models was that the productivity was higher in the retrospective analysis. There was a substantial predicted increase in biomass in the most recent years in the retrospective analysis that had recruitment anomalies set to 0 (Fig. 27). About half of the increase was due to the higher productivity estimate and the other half to the difference in recruitment anomaly.

The results of the delay difference production analysis were compared with those from the length-based assessment of Haist and Fournier (1998) (Fig. 28). The trends in biomass tended to be higher in the delay difference models than in the multifan analysis. One major difference between the models was that a higher natural mortality (M=0.6) was used in the multifan analysis. The main features were similar among the different models. Each predicted peak biomasses in the mid-1960s, mid-1970s, and late 1980s. The main differences among models are in the most recent years. The retrospective analysis suggests the stock size increased considerably in the late 1990s. This trend is opposite to the catch per unit effort series, the research vessel surveys, and all reports received from the industry. The last assessment indicated an increasing trend from 1994-1998. However, it is likely that this trend would have changed if the same analysis was run with the most recent data. The 2 production models using all available data indicate that the stock size is at an all time low.

The previous assessment of this stock (Sinclair 2000) used a non-equilibrium surplus production analysis. The current model, which includes a stochastic stock-recruitment relationship, resulted in a greatly improved fit to basically the same data. The residual mean square error about the main tuning index was considerably lower in the current model (0.08) than in the former model (0.19). The serial correlation of these residuals was also lower in the current model (0.29) than in the former model (0.53). This improvement in fit justifies moving to the new model.

4.3.2 Report Card

Indicators of biomass were in the danger and low categories (Table 13). Recruitment is at a low level but may be increasing. Fishing mortality and fishing effort on the stock were reduced in 2001 due to the reduced TAC, and this should aid stock recovery. Cod were taken entirely as by-catch in other fisheries in 2001. There have been some reports of increased recruitment in the third quarter of 2001, however there have been no requests for increases in TAC to allow higher catches in other fisheries.

There are few data available on secondary indicators. The size composition of commercial catches have not indicated a large mode passing through the population. This may be due in part to a low level of sampling in recent years. There has been a small reduction in fishing area in recent years, but some fishermen have indicated that Pacific cod are being found over a larger area then in past years. Information is lacking on changes in growth, maturity and condition. An environmental index which has been related to cod recruitment success, sea level at Prince Rupert, has become average to

favorable in the past 2 years following several years of unfavorable values. This may indicate improved recruitment conditions.

4.3.3 Current Status and Prognosis

The results of deterministic catch projections from the production models without and with sea level as a covariate are summarised in Fig. 29. A range of 2002 catches of 0-1500 t was used. The catch in 2001 was assumed to be 200 t. This was considered reasonable given the reported catch to date (Table 7). Three criteria were investigated. The first was the change in biomass between the beginning and end of 2002. With no catch in 2002, stock biomass is predicted to increase by between 30% and 40% in the 2 respective models. A catch of 1000 t and 1200 t would result in no change in biomass in the respective models. The second criterion was to compare the 2002 fishing mortality to F_{msy}. Catches of 600 t and 750t would result in F_{msy} in the 2 models. The third criterion was how close the surviving biomass would be to B_{msy}. With no catch in 2002, the surviving biomass would be approximately 20 % and 40% of B_{msy}.

Current stock biomass and recruitment is well below target. If the current TAC of 200 t is maintained for 2002, the stock biomass may increase by between 25-35 % and allow some stock rebuilding.

4.3.4 Uncertainties

This assessment depends to a large extent on the commercial catch per unit effort series as an index of stock size. It has been suggested on many occasions that recent changes in fishing strategies and management practices have introduced serious biases into the series possible making it an unreliable index of stock size. Indeed, it is clear that the fishery in the second quarter of 2001 was conducted in areas of low cod abundance. In anticipation of this trend continuing, it is very important to establish a fishery independent index of stock size in this area.

The Hecate Strait groundfish assemblage survey offers an alternative fishery independent index of stock size. However, it has proven to be a very imprecise index and of little use in following changes in stock size.

As was the case for the area 3CD stock, the possible the most serious weakness of the production analysis is in the estimation of biological reference points. There were the least robust to changes in model formulation. A second weakness is failure to account for changes in mesh size in the model and the effect this may have on recruitment estimates. These aspects warrant further investigation.

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6. References

Beverton, R.J.H., and Holt, S.J. 1957. On the dynamics of exploited fish populations. Fishery Investigations Series **(2) 19**: 533 p.

Boutillier, J.A., Yates, A.N., and Butler, T.N. 1976. G.B. Reed shrimp cruise 76-S-1, May 3-19, 1976. Fish. Mar. Ser. Data Rep. **13**: 46 p.

Butler, T.N., Yates, A.N., and Wood, C.C. 1973. G.B. Reed shrimp cruise 73-S-1, May 7-23, 1973. Fish. Res. Bd. Can. Man. Rep. Ser. **1255**: 46 p.

Fournier, D.A. 1983. An analysis of the Hecate Strait Pacific cod fishery using an age-structured model incorporating density-dependent effects. Can. J. Fish. Aquat. Sci. **40**: 1233-1243.

Haist, V., and Fournier, D. 1995. Pacific cod stock assessment for 1995 and recommended yield options for 1996. PSARC Working Paper **G95-3**.

Haist, V., and Fournier, D. 1998. Hecate Strait Pacific cod assessment for 1998 and recomended yield options for 1999. PSARC Working Paper **G98-3**.

Hilborn, R., and Walters, C.J. 1992. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York.

Richards, L.J., and Schnute, J.T. 2000. Science strategic project on the precautionary approach in Canada: Proceedings of the second workshop. Canadian Stock Assessment Proceedings Series **99/41**: 96 p.

Rutherford, K.L. 1999. A brief history of GFCATCH (1954-1995), the groundfish catch and effort database at the Pacific Biological Station. Can. Tech. Rept. Fish. Aqua. Sci. **2299**: 66p.

Schnute, J., and Haigh, R. 2000. Estimating stock biomass from tow-by-tow data for Pacific groundfish. Canadian Stock Assessment Secretariat Research Document **2000/155**: 35 p.

Sinclair, A.F. 2000. Assessment of Pacific cod in Hecate Strait, Nov. 2000. Canadian Stock Assessment Secretariat Research Document **2000/170**: 53.

Stocker, M., Hand, C., and McAllister, M.K. 1995. Pacific cod. in M. Stocker and J. Fargo ed. Groundfish stock assessments for the west coast of Canada in 1994 and recommended yield options for 1995. Can. Tech. Rept. Fish. Aqua. Sci. **2069**: 115-159.

Tyler, A.V., and Crawford, W.R. 1991. Modeling of recruitment patterns in Pacific cod (*Gadus macrocephalus*) in Hecate Strait, British Columbia. Can. J. Fish. Aquat. Sci. **48**: 2240-2249.

Tyler, A.V., and Foucher, R.P. 1990. Pacific cod in A.V. Tyler and J. Fargo, ed. Groundfish stock assessments for the west coast of Canada in 1989 and recommended yield options for 1990. Can. Tech. Rept. Fish. Aqua. Sci. **1732**: 59-94.

Walters, C.J., and Bonfil, R. 1999. Multispecies spatial assessment models for the British Columbia groundfish trawl fishery. Can. J. Fish. Aquat. Sci. **56**: 601-628.

Westrheim, S.J. 1996. On the Pacific cod (Gadus macrocephalus) in British Columbia waters, and a comparison with Pacific cod elsewhere, and Atlantic cod (G. morhua). Can. Tech. Rept. Fish. Aqua. Sci. **2092**: 390.

Westrheim, S.J., and Foucher, R.P. 1987. Stock assessment of Pacific Cod (Gadus macrocephalus) in Gerogia and Juan de Fuca Straits, 1954-84. Can. MS Rept. Fish. Aquat. Sci. **1905**: 353 p.

7. Tables

Table 1: Annual landings of Pacific cod by stock.

Year	Strait of Georgia	West Coast Vancouver Island	Queen Charlotte Sound	Hecate Strait	All Areas
1956	578	1468	1753	1046	4845
1957	607	1814	2744	1106	6271
1958	650	850	1178	3058	5736
1959	1047	907	946	2203	5103
1960	744	635	618	2360	4357
1961	415	420	240	1616	2691
1962	478	633	422	1690	3223
1963	675	1231	677	2927	5510
1964	713	1221	1275	5228	8437
1965	484	2768	1940	9119	14311
1966	297	3136	1811	9519	14763
1967	472	1941	1501	5112	9026
1968	349	1425	960	5165	7899
1969	388	1092	699	2987	5166
1970	502	1095	299	1315	3211
1971	740	3328	928	1477	6473
1972	630	5629	2320	2696	11275
1973	441	3712	1914	3996	10063
1974	681	3474	2292	4766	11213
1975	991	4000	2444	5036	12471
1976	927	3797	2271	4993	11988
1977	1148	2948	1268	3510	8874
1978	1373	1998	1959	2103	7433
1979	1202	1861	1904	4699	9666
1980	1611	1126	1383	4542	8662
1981	1749	896	853	3190	6688
1982	1012	1123	596	2066	4797
1983	904	694	183	2715	4496
1984	652	675	383	1748	3458
1985	463	492	299	1064	2318
1986	804	498	241	2099	3642
1987	1015	809	3243	8870	13937
1988	1223	1807	1849	6199	11078
1989	604	2991	763	4788	9146
1990	114	1953	772	3607	6446
1991	68	2177	2018	7655	11918
1992	412	2773	2043	5103	10331
1993	158	2527	1449	3965	8099
1994	90	1211	679	1561	3541
1995	24	652	345	1322	2343
1996	3	106	177	604	891
1997	7	99	162	1239	1507
1998	5	137	142	1097	1381
1999	6	72	117	629	824
2000	0	131	60	504	695

Table 2: Summary of recommended yields, TACs and landings (t) for Pacific cod off the west coast of Vancouver Island.

Year	Assessment Advice	TAC	Carryover	Catch	Comments
2001/02	No assessment/no advice	694	200	149	as of Oct. 15
2000/01	No assessment/no advice	694	205	130	
1999/00	Consider spawning closure	694		76	
1998/99	No assessment/ no advice	694		56	
1997/98	0	696		126	
1996	L: 694	by-catch only		109	
	H: 916				
1995	L: 1300	1300		652	
	M: 2200				
	H: 5330				
1994	L: 650	2170		1211	
	M: 2170				
	H: 5880				

Table 3: The number of measured fish and the number of samples (in brackets) of Pacific cod in commercial catches from the West Coast of Vancouver Island.

	number of fish (number of samples)							
Year	Q1		Q2		Q3		Q4	
1956	62	(1)	1869	(12)	528	(4)	291	(2)
1957	0	(0)	2577	(11)	1678	(8)	352	(1)
1958	0	(0)	1119	(6)	1348	(8)	965	(4)
1959	170	(1)	2470	(8)	1310	(6)	0	(0)
1960	0	(0)	942	(4)	1345	(5)	138	(1)
1961	0	(0)	2305	(8)	542	(2)	281	(2)
1962	0	(0)	2498	(9)	1554	(7)	0	(0)
1963	350	(1)	2746	(10)	671	(2)	524	(2)
1964	1163	(6)	2234	(9)	1238	(5)	184	(1)
1965	444	(2)	3239	(13)	1014	(4)	566	(2)
1966	2565	(10)	4453	(19)	2239	(11)	661	(3)
1967	1742	(7)	1949	(9)	0	(0)	411	(2)
1968	1832	(9)	594	(3)	0	(0)	745	(4)
1969	1337	(5)	1058	(4)	1056	(6)	1539	(8)
1970	1759	(9)	3313	(13)	2326	(9)	993	(4)
1971	1980	(9)	2950	(13)	2950	(13)	1292	(6)
1972	1671	(8)	2372	(9)	2312	(10)	867	(4)
1973	1338	(7)	2367	(11)	1277	(6)	179	(2)
1974	2211	(15)	2209	(10)	2434	(11)	1238	(6)
1975	2179	(13)	1533	(7)	793	(4)	344	(2)
1976	3267	(25)	706	(5)	657	(6)	0	(0)
1977	2766	(22)	586	(5)	840	(7)	236	(2)
1978	1713	(13)	944	(6)	120	(1)	120	(1)
1979	448	(3)	1676	(9)	839	(4)	0	(0)
1980	0	(0)	465	(4)	539	(4)	0	(0)
1981	0	(0)	342	(2)	120	(1)	0	(0)
1982	2248	(10)	498	(2)	269	(1)	158	(1)
1983	1122	(5)	186	(1)	0	(0)	0	(0)
1984	604	(3)	200	(1)	0	(0)	0	(0)
1985	0	(0)	561	(2)	0	(0)	254	(1)
1986	0	(0)	629	(3)	0	(0)	0	(0)
1987	400	(1)	400	(2)	0	(0)	0	(0)
1988	698	(2)	281	(1)	546	(1)	0	(0)
1989	1136	(3)	0	(0)	0	(0)	0	(0)
1990	373	(1)	0	(0)	0	(0)	0	(0)
1991	881	(5)	0	(0)	0	(0)	0	(0)
1992	1365	(6)	0	(0)	0	(0)	0	(0)
1993	1025	(7)	0	(0)	0	(0)	0	(0)
1994	1233	(4)	0	(0)	0	(0)	0	(0)
1995	200	(1)	0	(0)	0	(0)	0	(0)
1996	0	(0)	174	(1)	0	(0)	0	(0)
1997	0	(0)	0	(0)	0	(0)	0	(0)
1998	262	(1)	0	(0)	352	(2)	0	(0)
1999	0	(0)	302	(3)	124	(1)	0	(0)
2000	0	(0)	0	(0)	407	(3)	0	(0)
2001	0	(0)	2120	(15)	0	(0)	0	(0)

Table 4: Input observations and model predictions from the delay difference production model for west coast Vancouver Island Pacific cod.

	Observations			Predictions					Residuals	
Year	Effort	Catch	Weight	B	N	R	ϕ	F	Weight	Catch
1956	11665	1468	2.53	10289	3859	1625	-0.274	0.24	-0.051	-0.209
1957	9010	1814	2.30	8563	3608	1138	-0.498	0.19	-0.030	0.420
1958	4889	850	2.23	7994	3584	1120	-0.461	0.10	-0.001	0.303
1959	6938	907	2.49	7880	3256	1430	-0.206	0.14	0.027	0.052
1960	9647	635	2.60	7263	2965	2723	0.502	0.20	0.060	-0.527
1961	7276	420	2.49	6678	3019	4396	1.047	0.15	0.117	-0.597
1962	6795	633	1.98	7791	4422	2203	0.235	0.14	0.114	-0.277
1963	5236	1231	1.92	10884	6910	2747	0.213	0.11	0.199	0.300
1964	4493	1221	2.44	12883	6258	2799	0.122	0.09	0.169	0.269
1965	13750	2768	2.34	13953	6477	1912	-0.308	0.28	0.084	-0.025
1966	9038	3136	2.06	12557	5988	1973	-0.212	0.19	-0.017	0.582
1967	12428	1941	2.47	11862	5162	2421	0.029	0.26	0.072	-0.128
1968	17216	1425	2.58	10333	4584	4847	0.816	0.36	0.135	-0.582
1969	10299	1092	2.27	8926	4523	7455	1.352	0.21	0.142	-0.251
1970	7328	1095	1.84	11328	7238	4082	0.582	0.15	0.164	-0.174
1971	8807	3328	1.87	17230	11524	3944	0.302	0.18	0.226	0.348
1972	13548	5629	1.90	20093	10365	4231	0.302	0.28	-0.019	0.333
1973	12731	3712	2.23	18796	9069	3439	0.124	0.26	0.075	0.038
1974	10374	3474	2.14	17833	8791	3454	0.152	0.21	0.051	0.208
1975	15132	4000	2.22	17260	8080	3277	0.115	0.31	0.038	0.047
1976	19099	3797	2.20	15215	7320	2454	-0.108	0.39	0.055	-0.076
1977	15287	2948	2.35	12871	6504	1638	-0.413	0.32	0.172	0.027
1978	7670	1998	2.50	11538	5557	1227	-0.632	0.16	0.187	0.367
1979	5088	1841	2.36	11115	4740	1121	-0.698	0.11	0.007	0.708
1980	5017	1138	2.27	10422	4018	1031	-0.738	0.10	-0.134	0.305
1981	4691	899	1.99	9406	3490	1078	-0.621	0.10	-0.302	0.236
1982	13739	1129	2.18	8443	3103	1168	-0.461	0.28	-0.220	-0.418
1983	10567	697	1.94	6523	2606	1269	-0.176	0.22	-0.253	-0.410
1984	12696	678	1.88	5766	2538	1641	0.182	0.26	-0.192	-0.478
1985	16326	493	2.02	5277	2546	3597	1.041	0.34	-0.023	-0.925
1986	7555	499	2.51	5094	2829	2238	0.597	0.16	0.332	-0.189
1987	6569	813	2.04	7591	5180	1769	0.036	0.14	0.331	0.031
1988	7718	1813	2.08	9647	5196	1604	-0.241	0.16	0.113	0.443
1989	22562	3002	2.78	10048	4667	1707	-0.208	0.47	0.254	-0.032
1990	12263	1961	3.24	7476	3519	1842	0.088	0.25	0.421	0.356
1991	28360	2182	2.53	7105	3493	1039	-0.444	0.59	0.218	-0.183
1992	38287	2781	2.06	5481	3114	733	-0.581	0.79	0.158	0.103
1993	30796	2534	2.55	3522	1963	373	-0.873	0.64	0.352	0.607
1994	42648	1214	1.74	2585	1413	410	-0.496	0.88	-0.047	-0.046
1995	37809	657	2.48	1435	756	317	-0.200	0.78	0.267	0.009
1996	11511	106	1.29	1018	637	292	0.051	0.24	-0.217	-0.515
1997	5137	99		1164	645	587	0.619	0.11		0.035
1998	9816	137	1.75	1349	672	339	-0.074	0.20	-0.138	-0.393
1999	2957	72	1.49	1594	946	543	0.239	0.06	-0.123	-0.066
2000	2937	131	2.83	1921	921	514		0.06	0.304	0.349
2001		200	1.65	2237	1110	589			-0.200	

Table 5: Key parameter estimates from the delay-difference production analysis of the west coast Vancouver Island Pacific cod stock.

Parameter	All Years	To 1995
B_0	26,263	26,426
γ	0.39	0.48
M	0.42	0.46
δ	2.17	2.16
q	2.06E-5	1.65E-5
B_{msy}	12,615	11,531
F_{msy}	0.14	0.13
F_{crash}	0.31	0.34
ϕ	see Table 4	
s_0	0.28	0.31

Table 6: Report card summary of indicators for Pacific cod off the west coast of Vancouver Island

Report Card — **Pacific Cod in West Coast Vancouver Island**

Indicators			Knowledge Status			Observation	Interpretation re Reference Levels	Uncertainties	Stock Status			
Rating	Type	Index	Poor	Medium	High				Danger	Low	Neutral	Healthy
Primary	Biomass	Production Model				12% of Bo but increasing	Well below target stock size	Dependent on CPUE series	■			
		CPUE				Extremely Low but increasing	Well below target stock size	May be biased by changes in fishing practices	■	■		
		Shrimp Survey				Low but increasing	Below target stock size					
	Recruitment	Production Model				25% of optimum	insufficient to rebuild stock		■			
	Recruits/Spawners	Production Model				Recruitment anomalies above average for last 4 year-classes	Will aid recovery but need spawners					■
	Mortality	Fishing				Currently low	Will aid recovery					
		Natural				Estimated to be 0.6	No information on changes					
	Fishery	Catches			■	Small part of TAC taken, little hinderence on other fisheries	Mainly a by-catch fishery, abundance probably low			■		
		Effort (t-s)			■	Low effort in areas of cod distribution	Will aid recovery					■
	Stock Production Industry	SPM				Very low due to low stock size and low recruitment	Recovery requires low catch for several years			■		
	Preception	Port tech input				Low abundance				■		
		Pre-assessment input				increase in recent years from very low level						
Secondary	Size Structure	Commercial size		■		No sign of progressive mode	no large year-classes in popn			■		
	Maturity at Age			■		No information, no ageing	N/A					
	Growth	Condition Factor		■		No information						
		Weight at Age		■		No information, no ageing	N/A					
	Spatial Distribution	Fishing Distribution				25% reduction in fishery area, 1994 to present	Reduction in stock area	May reflect avoidance fishing				
	Predators	Main Predators		■		Little known about main predators						
	Prey Abundance			■		Little known about prey abundance						
	Oceanography			■		Little known about oceanographic influence on this stock						
Overall										■		

Table 7: Summary of recommended yields, TACs and landings (t) for Pacific cod in Hecate Strait.

Year	Assessment Advice	TAC	Carryover	Landings	Percent Caught
2001/02	Substantial reduction in catch	200		63	31% Oct. 15
2000/01	No new advice	1000	283	497	39%
1999/00	600-1500	1000		580	58%
1998/99	No directed fishery	1000		846	85%
1997/98	L: 1075	1620		1119	69%
	H:2165				
1996	0	by-catch only		403	
1995	L: 1870	1870		1322	71%
	M: 3040				
	H: 5520				
1994	L: 1670				
	M: 3850	3850		1561	41%
	H: 7790				
1993	L: 3200	5100		3965	78%
	H: 6500				
1992	L: 600	3400		5103	150%
	M: 2800				
	H: 3800				

Table 8: The number of measured fish and the number of samples (in brackets) of Pacific cod in commercial catches from Area 5CD, Hecate Strait.

	number of fish (number of samples)							
Year	Q1		Q2		Q3		Q4	
1956	481	(4)	560	(4)	296	(2)	0	(0)
1957	426	(3)	461	(3)	0	(0)	227	(1)
1958	2314	(13)	1209	(6)	664	(3)	2033	(10)
1959	4213	(20)	1949	(11)	3623	(16)	404	(2)
1960	1851	(9)	1840	(6)	3604	(15)	2031	(12)
1961	2778	(12)	4175	(16)	2743	(9)	1330	(6)
1962	4972	(18)	1488	(6)	1215	(4)	1093	(4)
1963	4607	(19)	3121	(11)	1403	(5)	1629	(6)
1964	4077	(19)	6332	(25)	3767	(14)	1649	(7)
1965	5993	(25)	5732	(21)	4040	(16)	2524	(11)
1966	3528	(14)	7459	(30)	3709	(15)	2131	(10)
1967	4341	(16)	2424	(9)	3580	(14)	3085	(15)
1968	3196	(14)	4701	(22)	2062	(9)	858	(4)
1969	2017	(10)	3561	(15)	1391	(7)	196	(1)
1970	1012	(5)	1145	(6)	713	(3)	172	(1)
1971	1692	(9)	1723	(9)	135	(1)	0	(0)
1972	458	(2)	804	(3)	548	(2)	1228	(6)
1973	682	(3)	2854	(11)	2727	(13)	1595	(10)
1974	451	(2)	2097	(10)	2151	(11)	2133	(10)
1975	2443	(14)	3206	(14)	120	(1)	884	(5)
1976	1590	(12)	1845	(15)	1051	(9)	457	(4)
1977	770	(6)	1793	(14)	2372	(20)	960	(8)
1978	816	(7)	2694	(21)	1316	(11)	797	(8)
1979	1656	(13)	3639	(23)	2500	(17)	634	(5)
1980	3774	(26)	2191	(16)	596	(5)	120	(1)
1981	0	(0)	120	(1)	478	(4)	240	(2)
1982	1576	(9)	2333	(10)	2192	(10)	228	(1)
1983	2807	(15)	3888	(20)	923	(4)	0	(0)
1984	1874	(8)	2170	(9)	1402	(6)	1259	(5)
1985	1723	(8)	1174	(5)	907	(4)	0	(0)
1986	1844	(8)	4120	(17)	416	(2)	236	(1)
1987	5497	(14)	2846	(7)	1406	(3)	540	(2)
1988	1689	(5)	1464	(4)	368	(1)	350	(1)
1989	752	(2)	731	(2)	0	(0)	400	(1)
1990	2583	(8)	231	(1)	912	(2)	789	(4)
1991	955	(6)	2475	(14)	756	(4)	147	(1)
1992	1697	(11)	1604	(10)	292	(2)	0	(0)
1993	873	(7)	1643	(13)	276	(2)	0	(0)
1994	945	(8)	348	(3)	116	(1)	0	(0)
1995	558	(5)	558	(5)	123	(1)	0	(0)
1996	0	(0)	404	(3)	569	(4)	0	(0)
1997	782	(8)	355	(3)	130	(1)	0	(0)
1998	1135	(11)	3791	(28)	1412	(13)	159	(1)
1999	676	(8)	1231	(10)	1002	(8)	0	(0)
2000	461	(4)	1002	(8)	142	(3)	310	(3)
2001	301	(2)	198	(4)				

Table 9: Input data for the delay difference production model of area 5CD (Hecate Strait) Pacific cod.

	Observations			
Year	Effort	Catch	Weight	Sea Level (cm)
1956	5980	992	2.71	
1957	4570	819	2.15	
1958	5679	2903	2.45	
1959	4481	1946	2.36	
1960	7936	2360	2.28	
1961	7412	1616	2.41	
1962	7161	1690	2.27	1396.6
1963	6518	2927	2.10	1399.2
1964	6249	5228	2.00	1400.2
1965	10137	9119	2.35	1396.1
1966	11081	9519	2.59	1403.0
1967	8574	5112	2.42	1400.5
1968	12161	5165	2.66	1406.0
1969	11440	2987	2.58	1401.3
1970	9485	1315	2.62	1403.3
1971	9263	1477	2.53	1394.1
1972	7133	2696	1.70	1397.8
1973	6165	3996	2.20	1404.8
1974	5730	4766	2.07	1398.7
1975	8896	5036	2.27	1398.5
1976	12340	4993	2.29	1400.5
1977	10736	3510	1.80	1402.2
1978	8135	2103	2.25	1406.4
1979	12034	4699	2.00	1398.1
1980	12673	4542	2.06	1402.9
1981	11200	3190	1.92	1410.2
1982	6868	2066	2.15	1399.0
1983	5920	2715	2.64	1414.4
1984	6529	1748	2.29	1407.8
1985	5770	1064	2.53	1396.3
1986	4366	2099	2.27	
1987	8855	8870	1.60	1407.5
1988	9818	6199	2.12	1400.9
1989	10614	4788	2.51	1394.1
1990	10521	3607	2.22	1400.1
1991	17867	7655	2.15	1398.6
1992	17736	5103	2.40	1417.4
1993	19863	3965	2.86	1411.3
1994	13783	1561	3.06	1401.1
1995	12490	1322	2.99	1403.8
1996	4640	397	2.34	1400.4
1997	7816	1241	3.07	1399.7
1998	8081	1099	3.00	1413.2
1999	8432	629	2.59	1404.8
2000	7702	502	3.26	1402.7
2001		200	2.74	1400.3

Table 10: Model predictions from a delay difference model of area 5CD Pacific cod that includes a sea level effect.

	Predictions					Residuals	
Year	Biomass	Numbers	Recruits	ϕ	F	Weight	Catch
1956	6268	1615	2384	0.46	0.25	-0.36	-0.22
1957	6659	3391	1337	-0.16	0.19	0.09	-0.23
1958	8811	4624	1507	-0.18	0.23	0.25	0.56
1959	9872	4255	1703	-0.10	0.18	0.02	0.26
1960	10699	4329	2478	0.25	0.33	-0.08	-0.13
1961	10064	4193	3624	0.65	0.31	0.00	-0.39
1962	10469	4941	9178	0.89	0.30	0.07	-0.35
1963	12333	6558	3265	0.12	0.27	0.11	0.11
1964	19519	13176	2329	-0.09	0.26	0.30	0.27
1965	24219	11388	2566	-0.38	0.42	0.10	0.20
1966	20995	8310	1320	-0.30	0.46	0.02	0.31
1967	16909	6763	1571	-0.48	0.35	-0.03	0.12
1968	14353	5109	1068	-0.22	0.50	-0.05	0.01
1969	10578	4039	2081	-0.05	0.47	-0.01	-0.18
1970	8120	3078	3816	0.90	0.39	-0.01	-0.59
1971	7726	3742	5278	0.16	0.38	0.21	-0.40
1972	9547	5853	2961	-0.08	0.29	0.04	0.21
1973	14018	8757	1412	-0.08	0.25	0.32	0.34
1974	17341	8378	2493	-0.22	0.24	0.00	0.37
1975	17742	6689	2906	-0.09	0.37	-0.15	0.03
1976	15476	6190	2400	-0.06	0.51	-0.09	-0.11
1977	12795	5874	2947	0.36	0.44	-0.19	-0.16
1978	11711	5410	1565	0.24	0.34	0.04	-0.36
1979	12375	6033	3470	0.05	0.50	-0.03	0.07
1980	10452	4495	1994	0.10	0.52	-0.12	0.17
1981	10003	5596	770	0.02	0.46	0.07	-0.05
1982	9820	4807	2641	-0.05	0.28	0.05	-0.05
1983	9646	3659	532	0.16	0.24	0.00	0.37
1984	10450	4928	2027	0.69	0.27	0.08	-0.24
1985	10000	3535	9493	0.90	0.24	-0.11	-0.58
1986	10069	4250	1948	0.03	0.18	-0.04	0.34
1987	17457	12325	1182	0.06	0.37	0.12	0.61
1988	19317	8772	2772	0.16	0.40	-0.04	0.07
1989	16154	5849	5248	-0.02	0.44	-0.10	-0.08
1990	13496	5784	2171	-0.20	0.43	-0.05	-0.17
1991	14391	8238	1885	-0.52	0.74	0.21	0.12
1992	10826	5316	305	-0.08	0.73	0.16	0.00
1993	7911	3925	510	-0.16	0.82	0.35	-0.01
1994	4525	1685	932	-0.43	0.57	0.13	-0.13
1995	3205	1272	538	-0.40	0.52	0.17	0.13
1996	2903	1538	562	-0.68	0.19	0.21	-0.13
1997	3473	1551	643	-0.77	0.32	0.32	0.36
1998	3407	1459	229	-0.20	0.33	0.25	0.23
1999	3336	1476	591		0.35	0.14	-0.34
2000	2934	1061	853		0.32	0.16	-0.36
2001	2783	1208	1083		0.08	0.17	

Table 11: Model predictions from a delay difference model of area 5CD Pacific cod that does not includes a sea level effect.

	Predictions					Residuals	
Year	Biomass	Numbers	Recruits	ϕ	F	Weight	Catch
1956	6711	1705	2416	0.60	0.24	-0.37	-0.25
1957	7079	3497	1308	-0.06	0.18	0.06	-0.25
1958	9268	4759	1607	-0.08	0.22	0.23	0.55
1959	10356	4360	1856	-0.02	0.18	-0.01	0.25
1960	11285	4539	2707	0.29	0.31	-0.09	-0.15
1961	10826	4519	4849	0.90	0.29	0.01	-0.43
1962	11477	5413	5057	0.90	0.28	0.07	-0.41
1963	14434	8124	3124	0.25	0.26	0.17	-0.01
1964	18779	10097	2649	-0.08	0.25	0.07	0.35
1965	21360	9456	2250	-0.32	0.40	0.04	0.36
1966	18969	7734	1819	-0.46	0.44	0.05	0.45
1967	15731	6257	1582	-0.49	0.34	-0.04	0.23
1968	14077	5399	1576	-0.41	0.48	0.02	0.06
1969	10933	4263	1861	-0.06	0.45	0.01	-0.19
1970	9045	3754	5465	1.16	0.37	0.08	-0.66
1971	8635	3933	2460	0.40	0.37	0.14	-0.48
1972	11629	7655	2513	0.19	0.28	0.11	0.05
1973	14460	7095	2233	-0.08	0.24	0.08	0.35
1974	15980	6976	2295	-0.12	0.23	-0.10	0.49
1975	16695	6698	2711	0.01	0.35	-0.09	0.12
1976	15118	6078	2353	-0.06	0.49	-0.08	-0.06
1977	12702	5708	2838	0.25	0.42	-0.21	-0.12
1978	11754	5352	2363	0.12	0.32	0.02	-0.33
1979	12461	5953	2438	0.11	0.47	-0.05	0.10
1980	11344	5334	2081	0.02	0.50	-0.03	0.12
1981	10293	5033	1626	-0.15	0.44	-0.06	-0.04
1982	9821	4677	1655	-0.10	0.27	0.02	-0.02
1983	10406	4488	1980	0.04	0.23	0.13	0.33
1984	10916	4505	3926	0.69	0.26	-0.06	-0.25
1985	11239	4774	4637	0.83	0.23	0.07	-0.66
1986	13555	6977	2477	0.07	0.17	0.15	0.08
1987	18138	9350	2530	-0.11	0.35	-0.19	0.61
1988	18089	7767	2950	0.05	0.39	-0.09	0.17
1989	16296	6760	3007	0.13	0.42	0.04	-0.05
1990	14664	6518	2027	-0.19	0.42	-0.01	-0.22
1991	13853	6460	1397	-0.52	0.71	0.00	0.18
1992	9880	4588	914	-0.69	0.70	0.11	0.12
1993	7025	3225	762	-0.60	0.78	0.27	0.13
1994	4574	2095	681	-0.33	0.54	0.34	-0.11
1995	3788	1738	539	-0.39	0.49	0.32	-0.01
1996	3317	1533	447	-0.46	0.18	0.08	-0.23
1997	3744	1563	491	-0.48	0.31	0.25	0.32
1998	3514	1368	466	-0.47	0.32	0.16	0.24
1999	3246	1290	568		0.33	0.03	-0.28
2000	2993	1208	642		0.30	0.27	-0.34
2001	2960	1283	636		0.08	0.17	

Table 12: Key parameter estimates from the delay-difference production analysis of the area 5CD (Hecate Strait) Pacific cod stock.

Parameter	All Years, no Sea Level	All Years, Sea Level	To 1995, Sea Level
B_0	52,153	29,441	21,903
γ	0.13	0.21	0.32
M	0.23	0.23	0.29
δ	4.89	7.00	12.56
q	3.88E-5	4.12E-5	3.64E-5
L		-0.64	-0.70
Objective Function			
Rec	-16	-20	-29
Wt	-62	-60	-61
Cat	-21	-27	-38
Total	-99	-107	-128
B_{msy}	23,648	13,040	9,413
F_{msy}	0.19	0.25	0.51
F_{crash}	0.46	0.67	2.03
ϕ	see Table 10	see Table 11	
s_0	0.23	0.37	0.94

Table 13: Report card summary of indicators for Pacific cod in area 5CD.

Report Card — **Pacific Cod in Area 5CD, Hecate Strait**

Indicators			Knowledge Status			Observation	Interpretation re. Reference Levels	Uncertainties	Stock Status			
Rating	Type	Index	Poor	Medium	High				Danger	Low	Neutral	Healthy
Primary	Biomass	Production Model				6-9% of B0	Well below target stock size	Dependent on CPUE series	■			
		CPUE				Lowest in time series	Well below target stock size	May be biased by changes in fishing practices	■			
		Trawl Survey	■			Low	Below target stock size			■		
	Recruitment	Production Model				Low but increasing	Insufficient to rebuild stock			■		
	Recruits/Spawners	Production Model				Recruitment anomalies below average for last 9 year-classes	Suggests recruitment failure	Estimates may be biased downward by change in		■		
	Mortality	Fishing				Low in 2001 because of TAC reduction	Will aid recovery					■
		Natural				Estimated to be 0.25	No information on changes					
	Fishery	Catches			■	Low TAC in 2001 hindering other fisheries	Completely a by-catch fishery, abundance probably low					
		Effort (f-s)			■	Low effort in areas of cod distribution	Will aid recovery					■
	Stock Production	SPM				25-40% of maximum	Recovery requires low catch for several years			■		
	Industry Preception	Part tech input				Low abundance						
		Pre-assessment input				Low abundance in early 2001, some signs of young fish	May be an improvement in recruitment					
Secondary	Size Structure	Commercial size				No sign of progressive mode	no large year-classes in popln			■		
	Maturity at Age		■			No information, no ageing	N/A					
	Growth	Condition Factor	■			No information						
		Weight at Age	■			No information, no ageing	N/A					
	Spatial Distribution	Fishing Distribution				25% reduction in fishery area, 1994 to present	Reduction in stock area	May reflect avoidance fishing				
	Predators	Main Predators	■			Little known about main predators						
	Prey Abundance		■			Little known about prey abundance						
	Oceanography					Sea level index average in 2000 and below average in 2001	Improved conditions for recruitment					■
Overall										■		

8. Figures

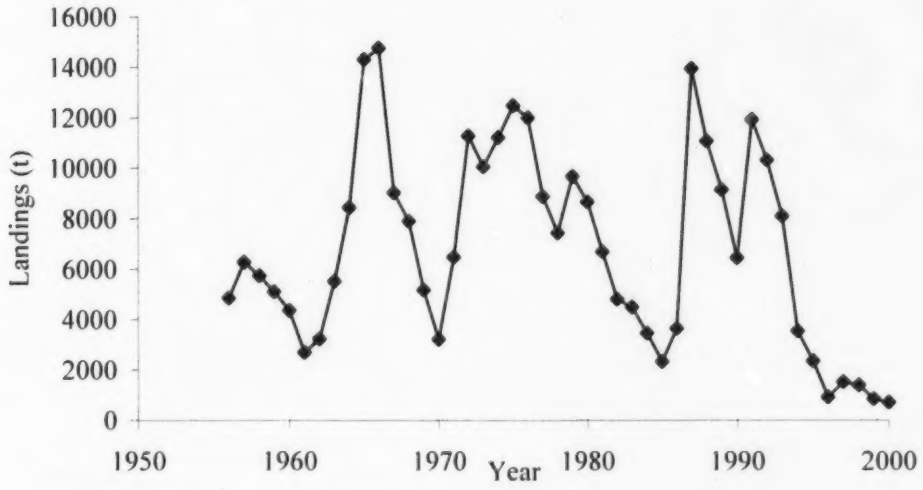


Figure 1: Annual landings of Pacific cod off the BC coast.

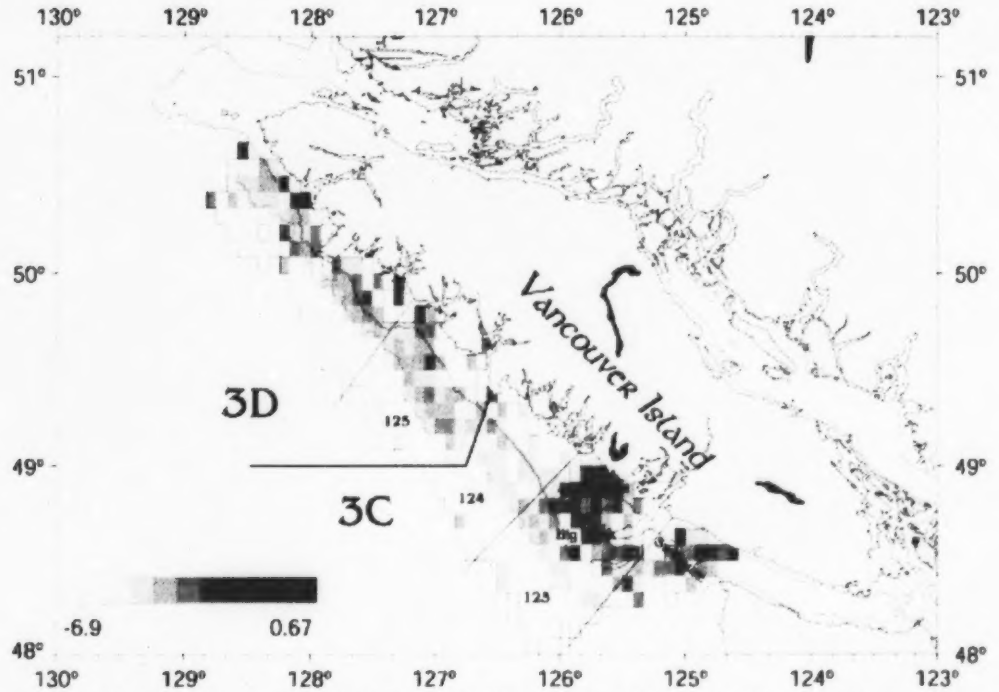


Figure 2: Groundfish trawl catch per unit effort of Pacific cod off the west coast of Vancouver Island. Shaded rectangles are where cod were caught, shading is on a ln scale. The total fishing area is outlined. Depth contours are shown for 100, 500, and 1500 m. Selected groundfish management area boundaries are also shown.

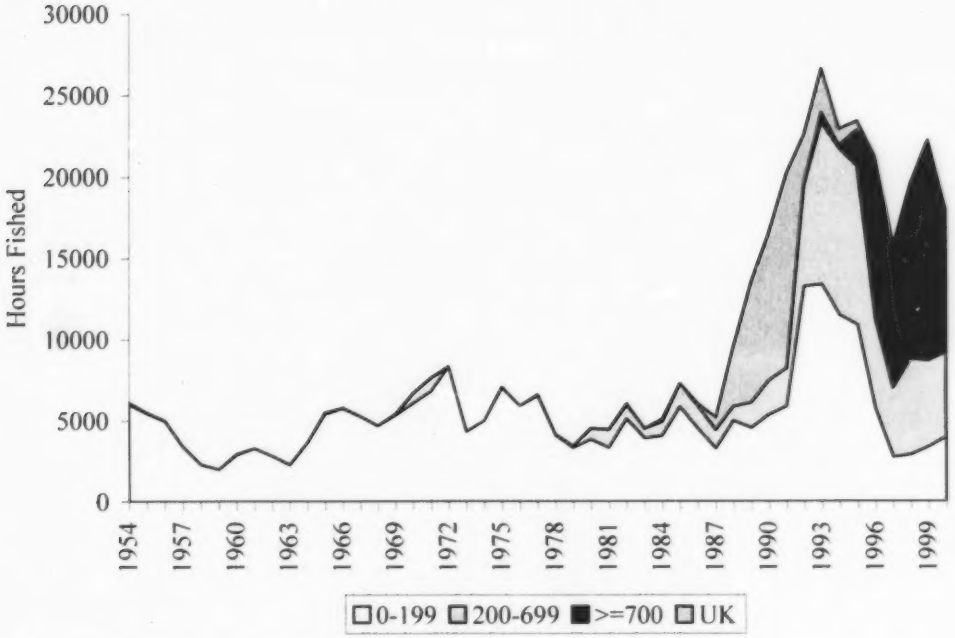


Figure 3: Distribution of trawl fishing effort by depth zone off the west coast of Vancouver Island, 1954-2000.

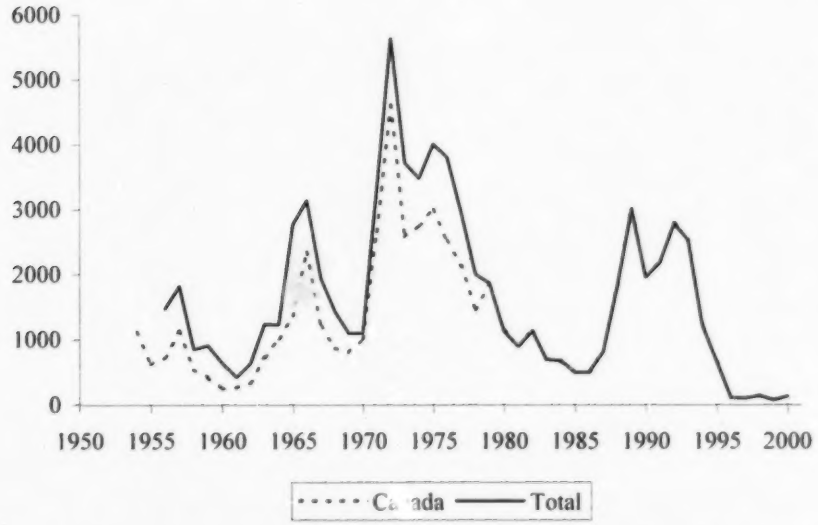


Figure 4: Annual landings of Pacific cod off the west coast of Vancouver Island (Area 3CD), 1954-2000.

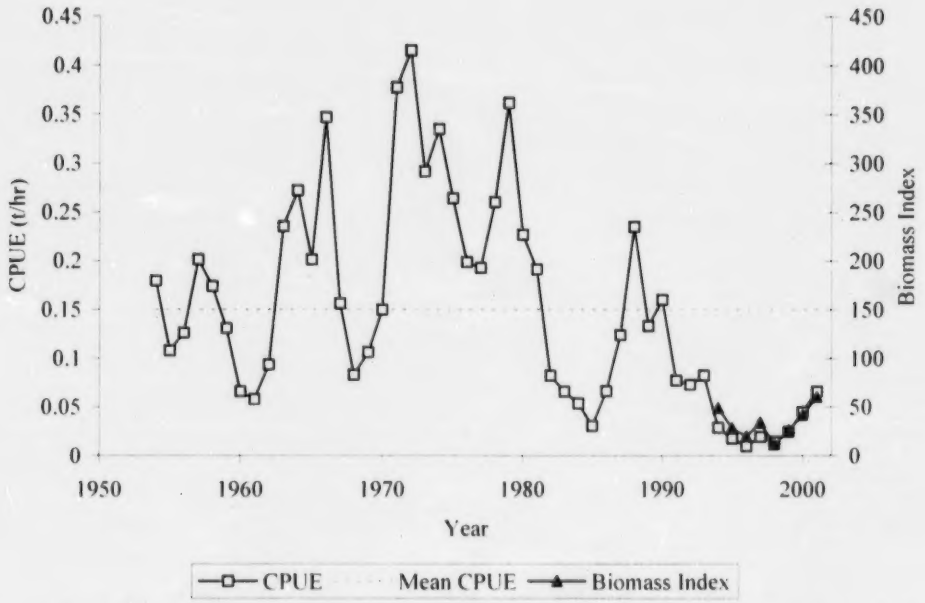


Figure 5: Catch per unit effort and swept area biomass indices of Pacific cod abundance off the west coast of Vancouver Island.

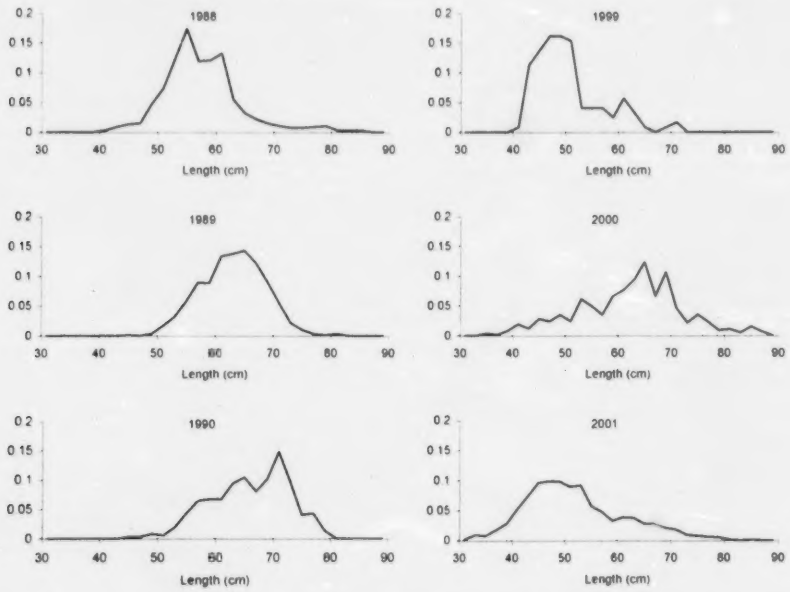


Figure 6: Size composition (proportions) of commercial catches of Pacific cod off the west coast of Vancouver Island. Samples were from the first quarter of 1988, 1989, and 1990 and the second quarter of 1999, 2000, and 2001.

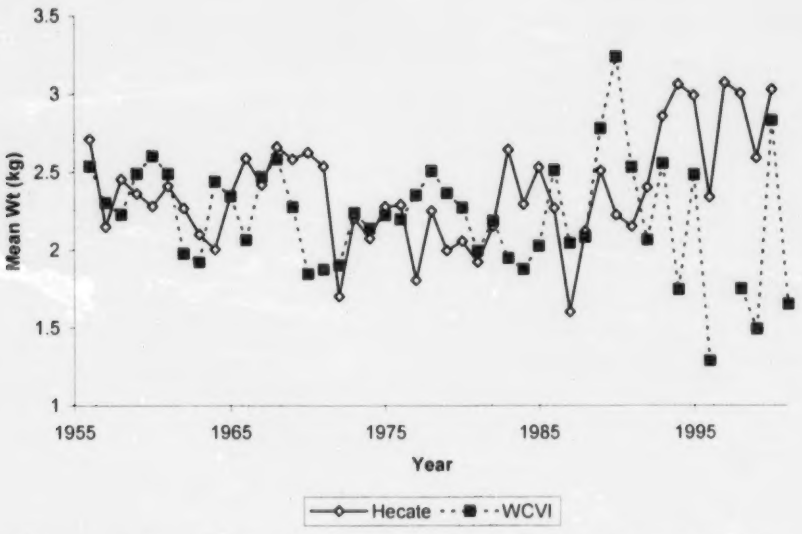


Figure 7: Mean weights of individuals in the commercial catches of Pacific cod off the wesc coast of Vancouver Island (WCVI) and hecate Strait.

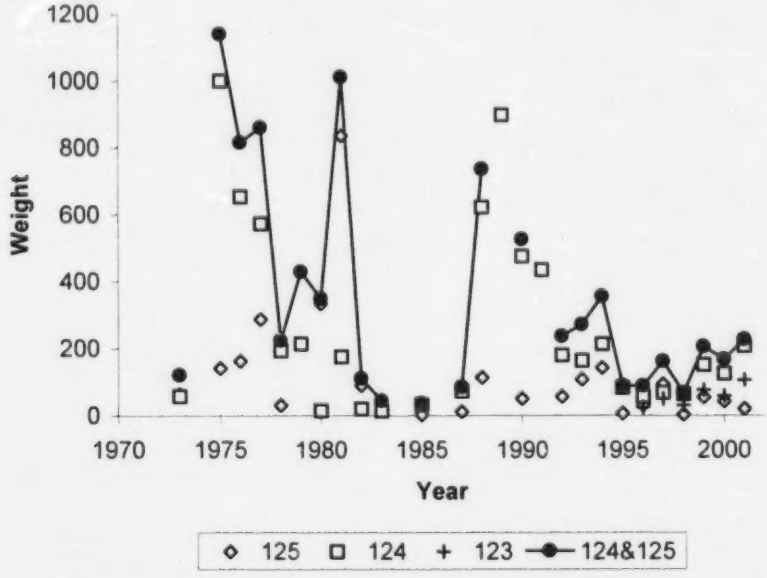


Figure 8: Indices of Pacific cod biomass obtained from shrimp surveys off the west coast of Vancouver Island. The survey areas (123, 124, 125) are shown in Fig. 2.

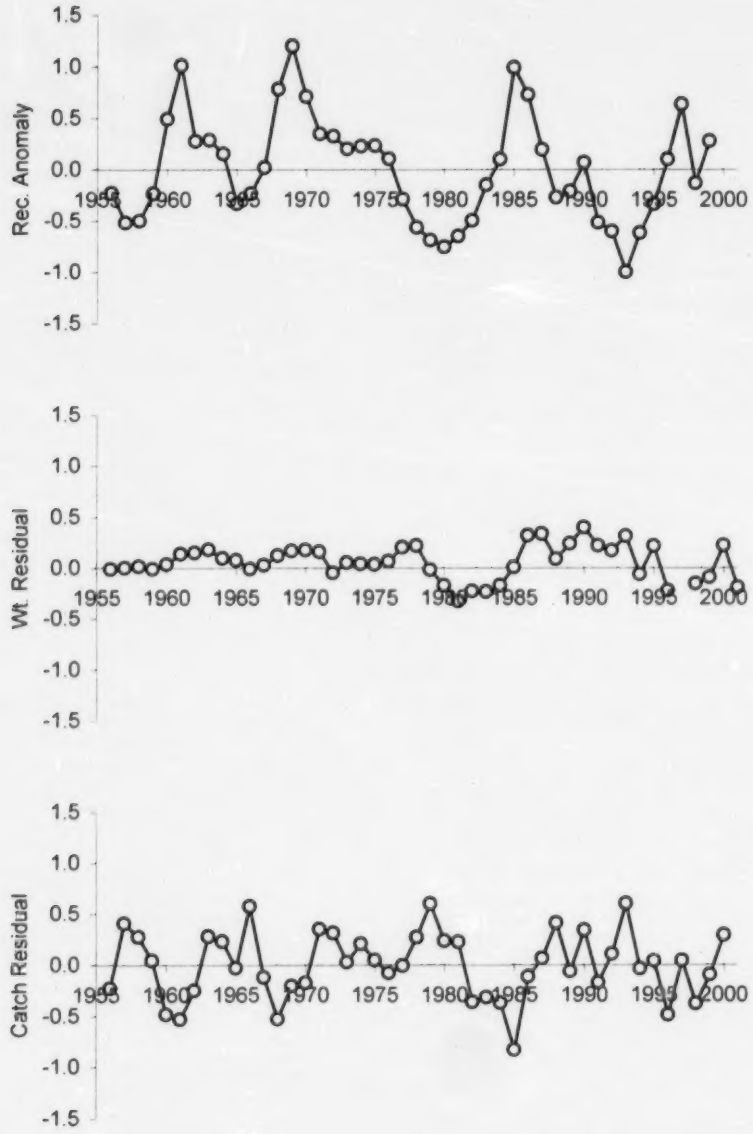


Figure 9: Recruitment anomalies, mean weight residuals, and catch residuals from the delay difference production analysis of west coast Vancouver Island Pacific cod.

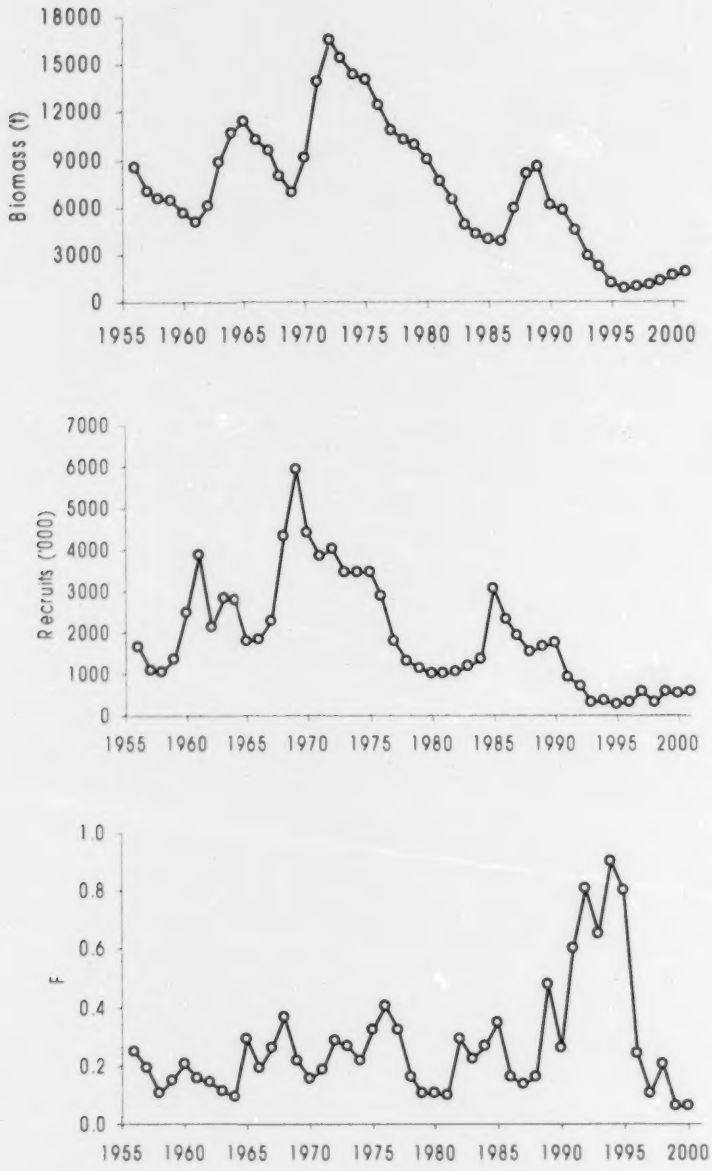


Figure 10: Predicted biomass, recruitment, and fishing mortality for west coast Vancouver Island Pacific cod.

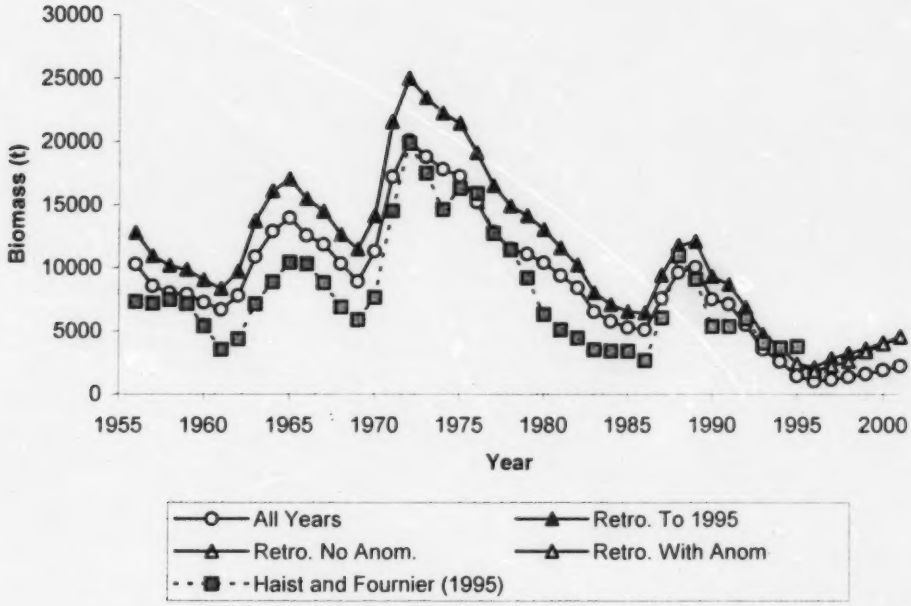


Figure 11: Comparison of predicted biomass from 3 analyses of Pacific cod off the west coast of Vancouver Island. Biomass projections in the retrospective analysis were done with and without recruitment anomalies predicted in the analysis with all years' data.

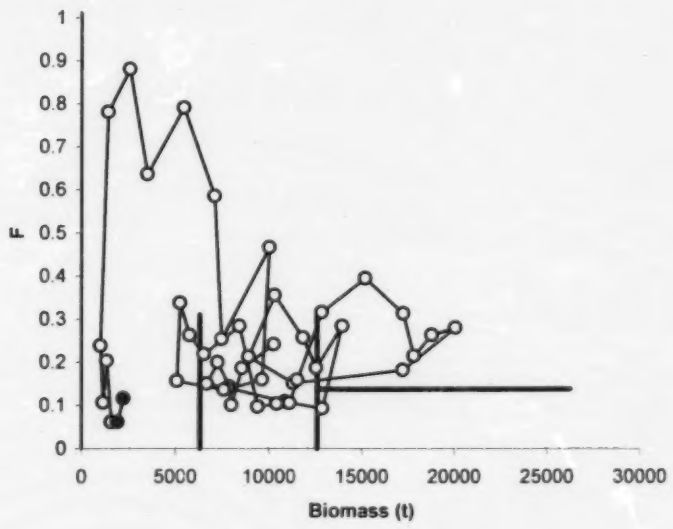


Figure 12: Phase plot of predicted biomass and fishing mortlaity for west coast Vancouver Island Pacific cod. The vertical lines begin at B_{msy} and 0.5 B_{msy} and terminate at F_{crash}. The horizontal line is at F_{msy} and terminates at B_0. The final 2 years (2000, 2001) are indicated by solid circles.

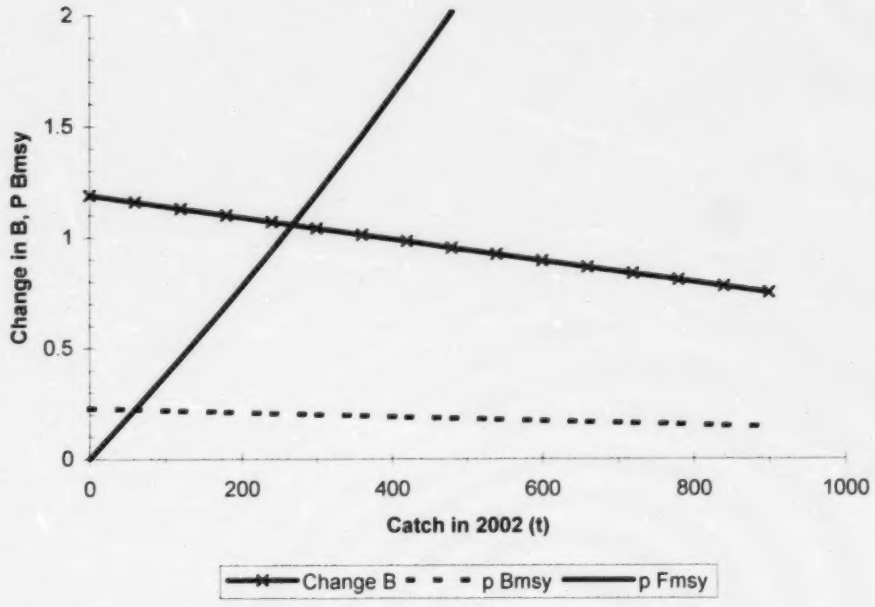


Figure 13: Summary of catch forecasts for west coast Vancouver Island Pacific cod. Three criteria are presented relative to the catch in 2002. The solid line with tick-marks gives the proportional change in stock biomass between 2002 and 2003. The dashed line indicates the proportion of F_{msy} that will result from the given catch. The solid line indicates the fraction of B_{msy} that will be present in 2003.

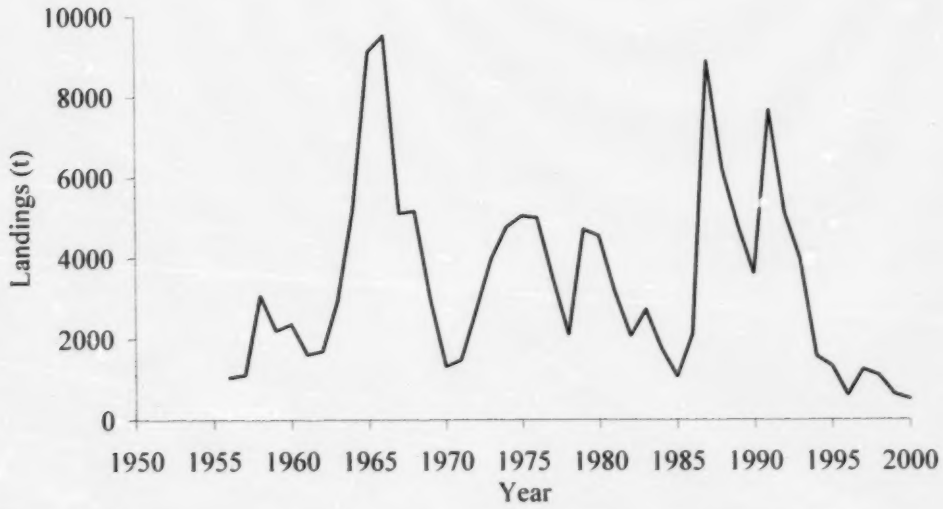


Figure 14: Landings of Pacific cod from the Hecate Strait stock, 1956-2000.

Figure 15: Major groundfish trawl fishing grounds in areas 5CD. The 100 m depth contour is shown.

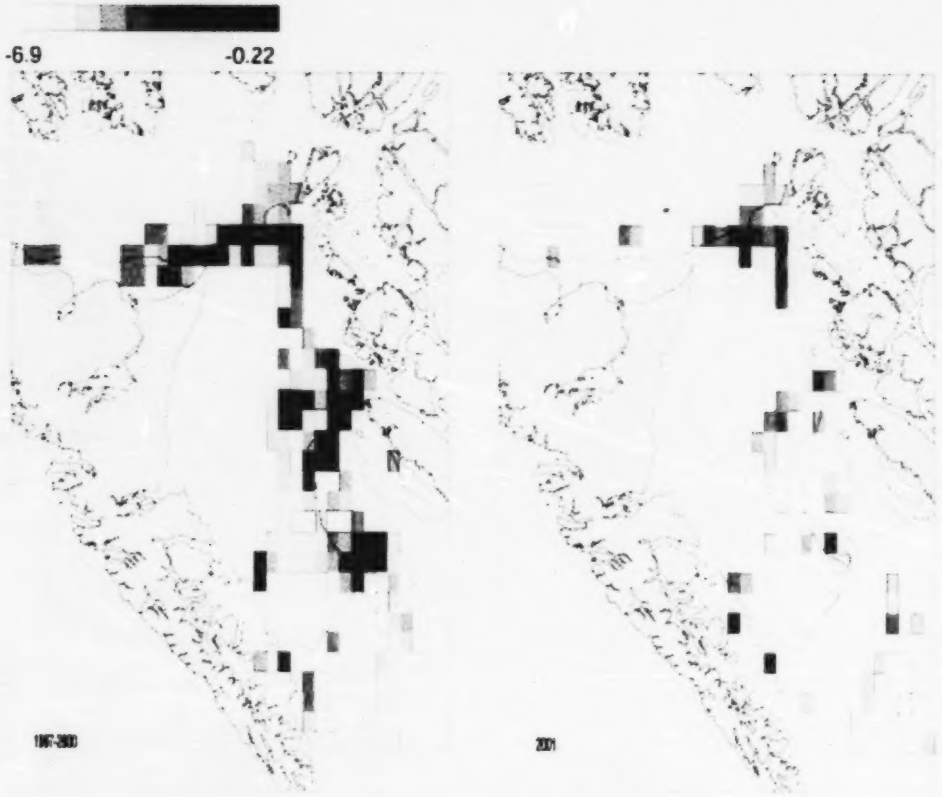


Figure 16: Distribution of Pacific cod during quarter 2 of 1997-2000 (left panel) and 2001. The rectangles are shaded to represent catch per unit effort (ln $t \cdot hr^{-1}$).

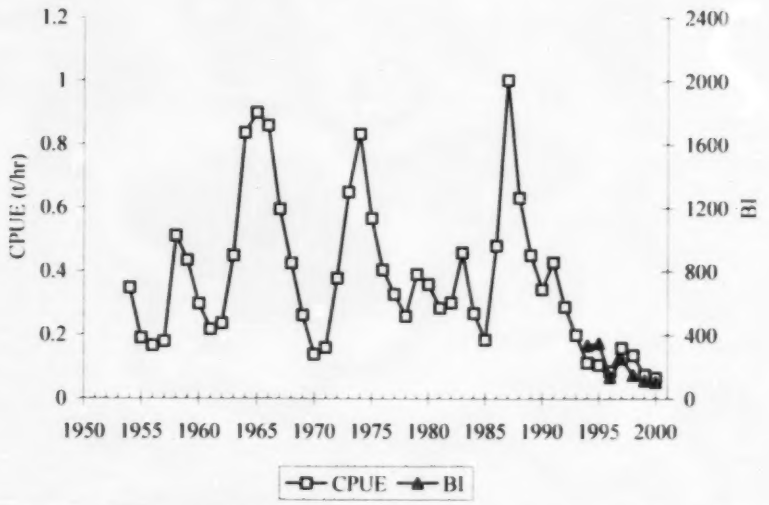


Figure 17: Catch per unit effort and swept area biomass indices of Pacific cod abundance in Hecate Strait, area 5CD, 1954-2000.

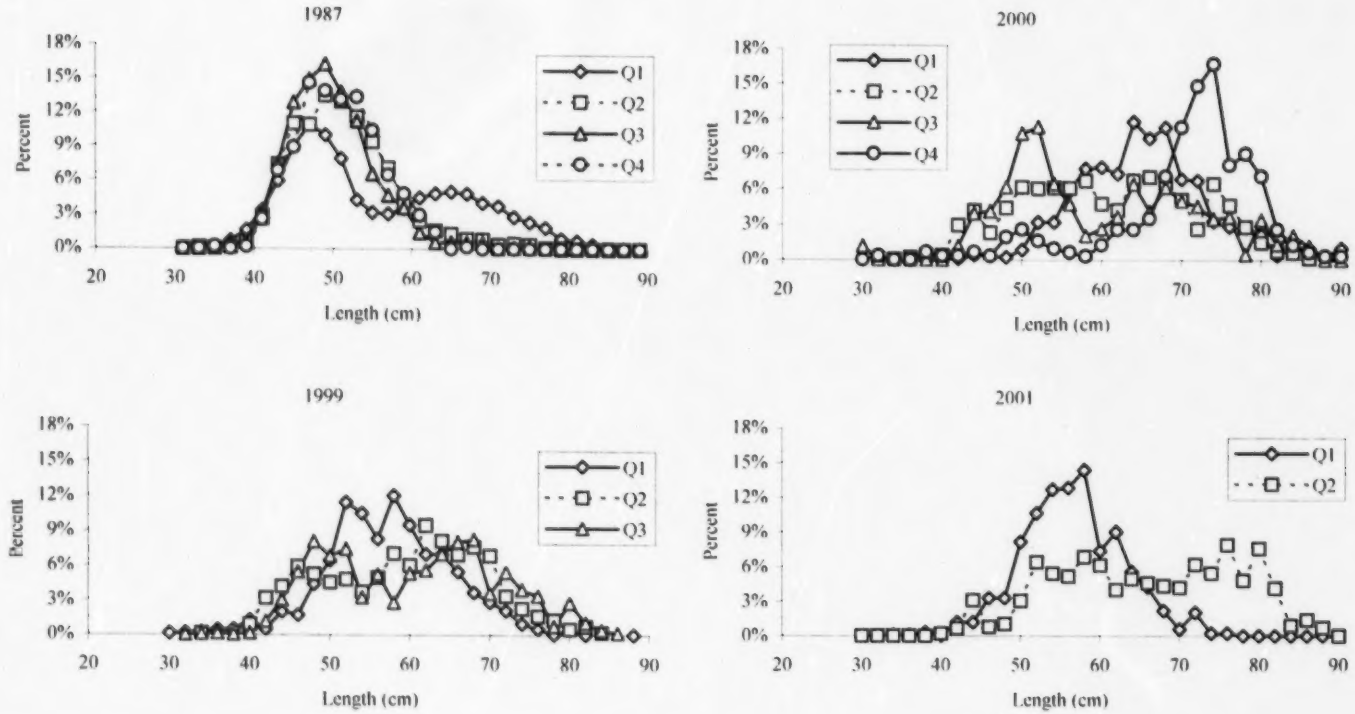


Figure 18: Quarterly length frequencies (percent) for Pacific cod in area 5CD, 1987, 1999-2001.

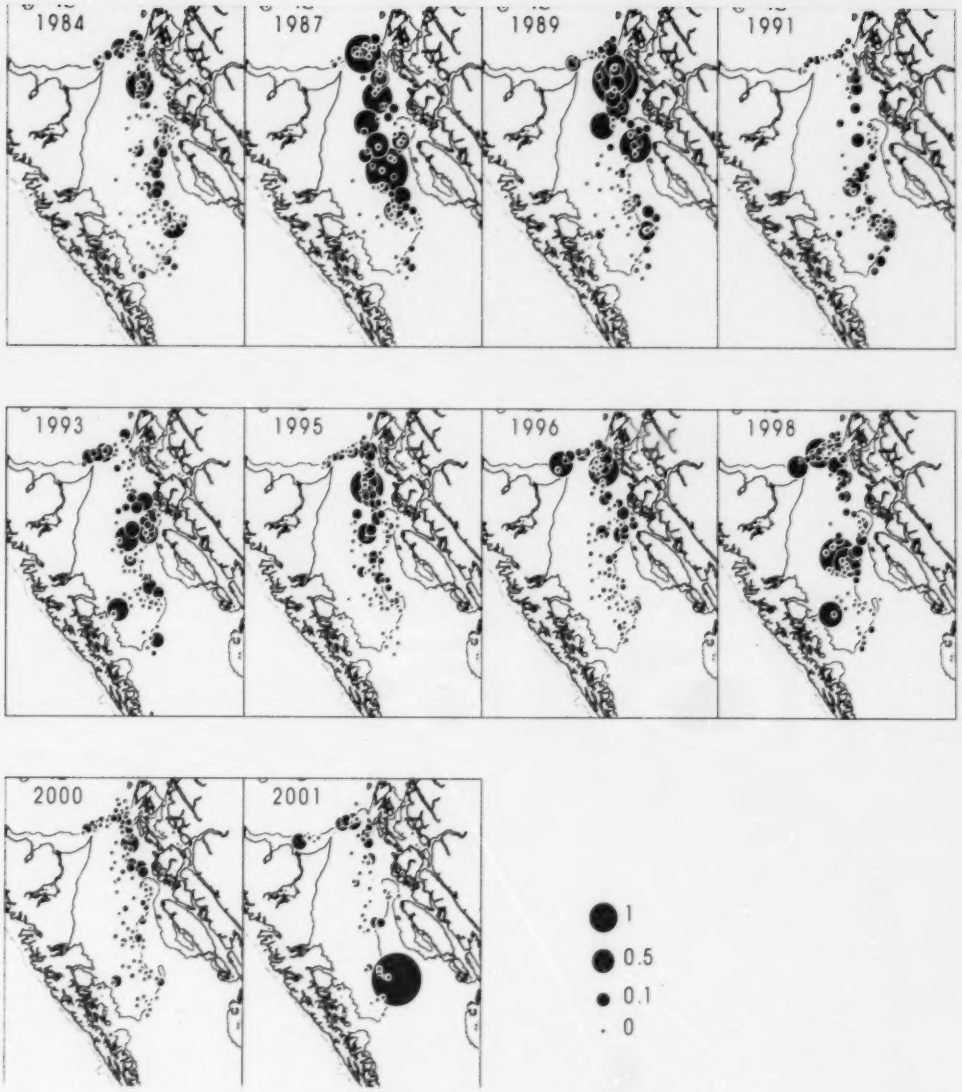


Figure 19: Catches of Pacific cod during the Hecate Strait groundfish assemblage surveys, 1984-2000 and a biological sampling survey in 2001. The symbols represent catch rates ($t \cdot hr^{-1}$). The 100 m, 500 m, and 1500 m depth contours are shown.

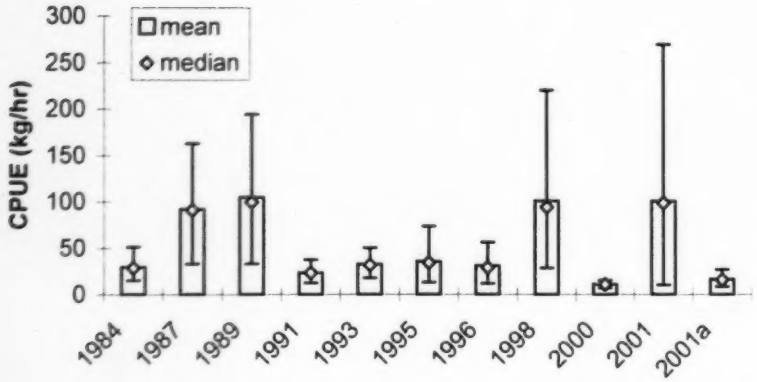


Figure 20: Mean catch per unit effort (kg·hr-1) of Pacific cod in the Hecate Strait groundfish assemblage surveys (1984-2000) and the 2001 groundfish biological survey. The distributions of the means were determined by bootstrapping. The vertical lines give the 95% confidence limits. The data labeled 2001 include all sets in the survey. The data labeled 2001a exclude one exceptionally large set made in the Horseshoe area.

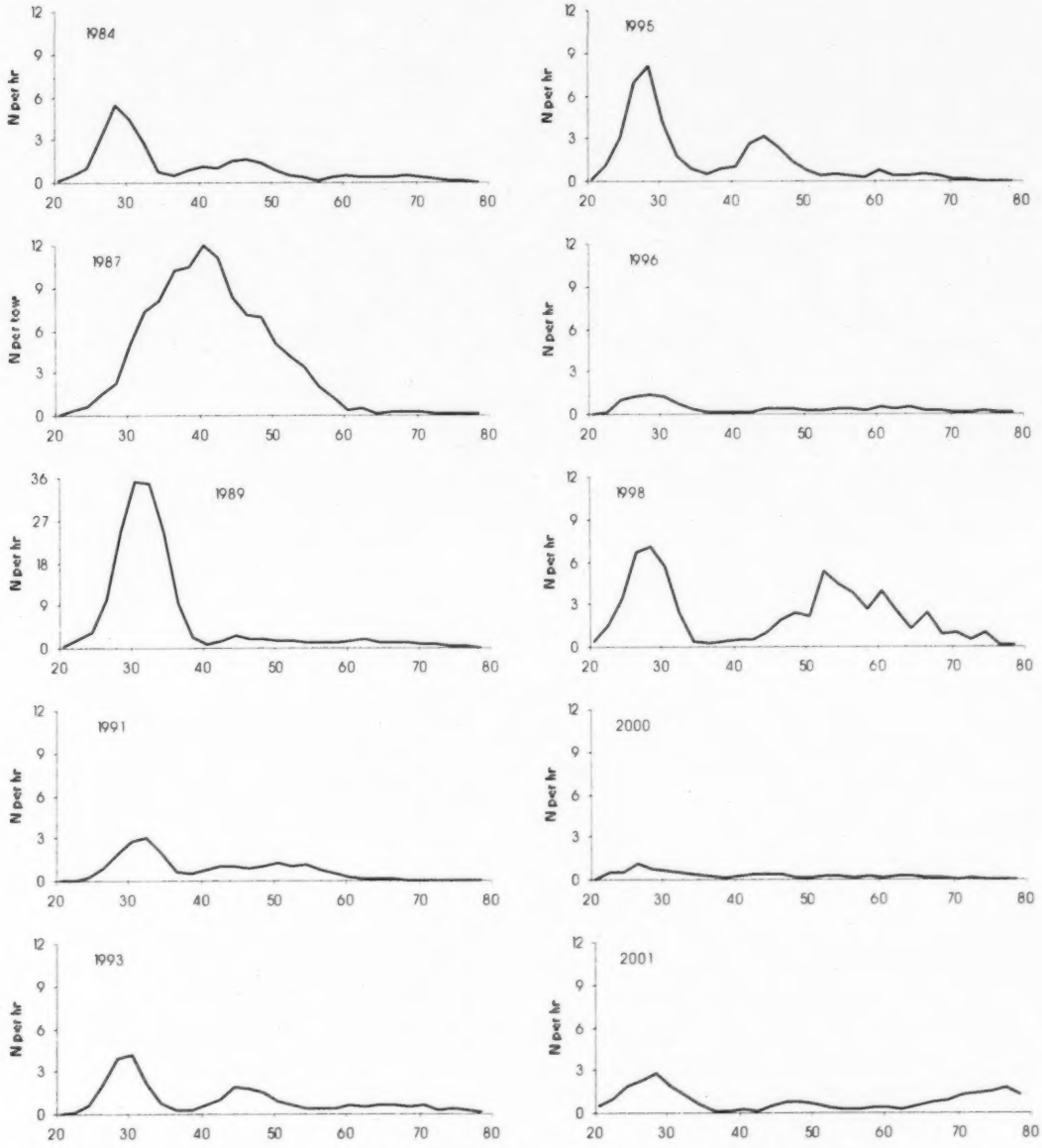


Figure 21: Length composition of Pacific cod in the groundfish assemblage surveys 1984-2000 and the 2001 groundfish biological survey. The graphs are scaled to numbers per hour fished and indicate both size coposition and relative abundance. Note that the scale of the 1989 panel is different that the others.

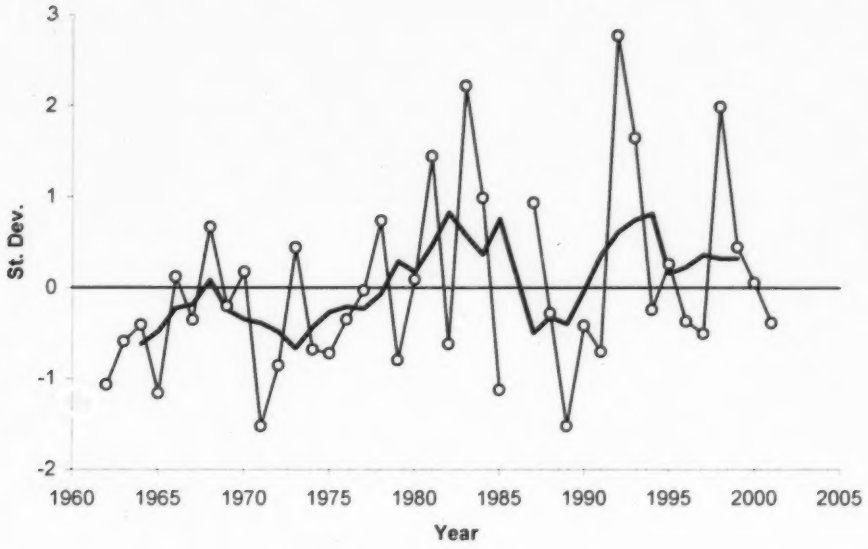


Figure 22: Average winter (Jan.-Mar.) sea level (cm) in Prince Rupert, adjusted for air pressure and sea level rise. The annual data are plotted as standard deviates from the overall mean of 1402 cm (st. dev = 5.4 cm). Data supplied by W. Crawford, Institute of Ocean Sciences, DFO, Sidney, BC.

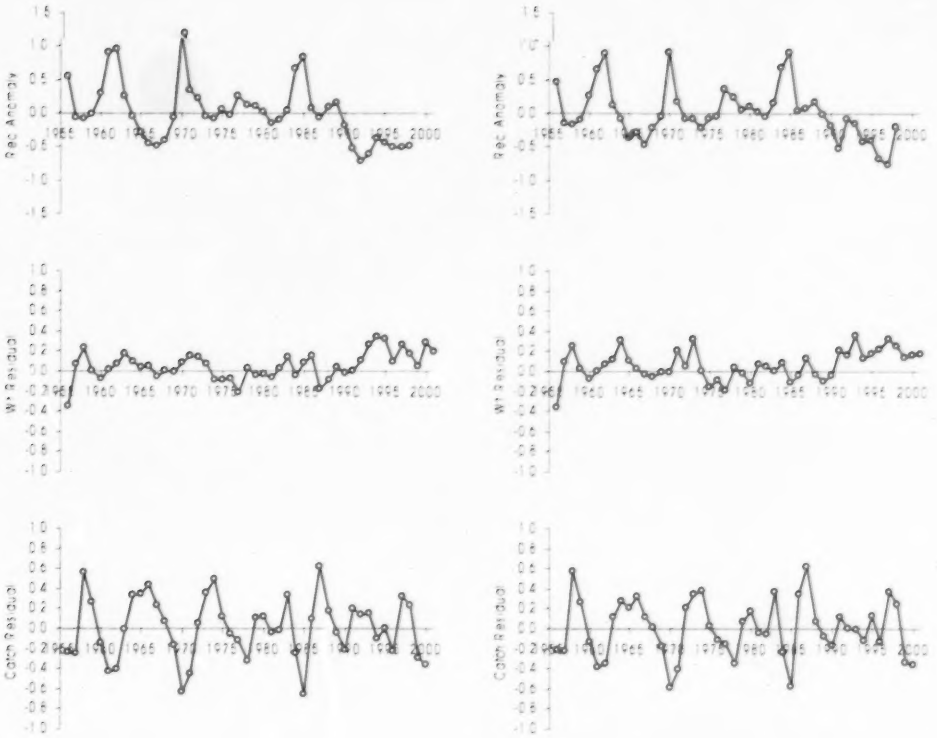


Figure 23: Recruitment anomalies, mean weight residuals and catch residuals from delay difference production models of area 5CD Pacific cod. The right side give results fro a model with sea level as a covatiate.

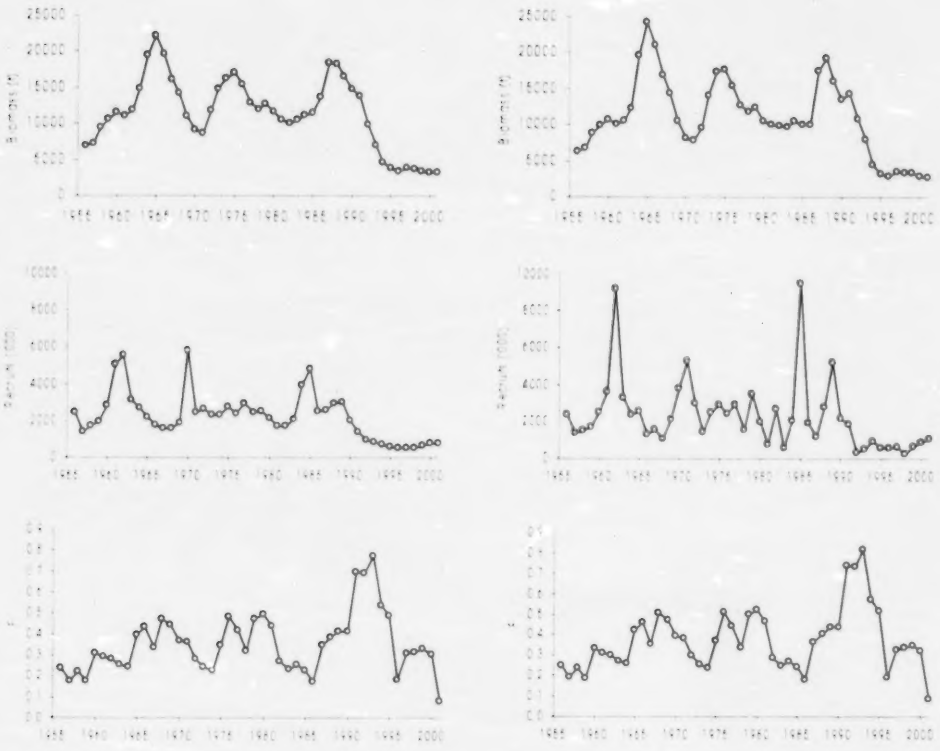


Figure 24: Predicted biomass, recruitment, and fishing mortality from delay difference production models of area 5CD (Hecate Strait) Pacific cod. The panels on the right are from a model that includes sea level height as a covariate.

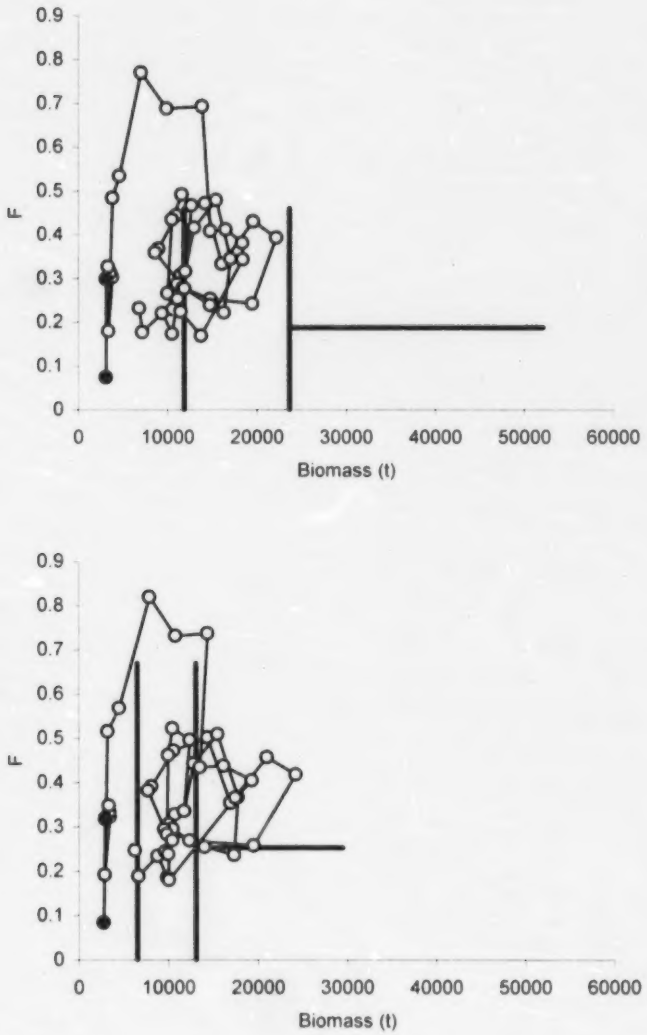
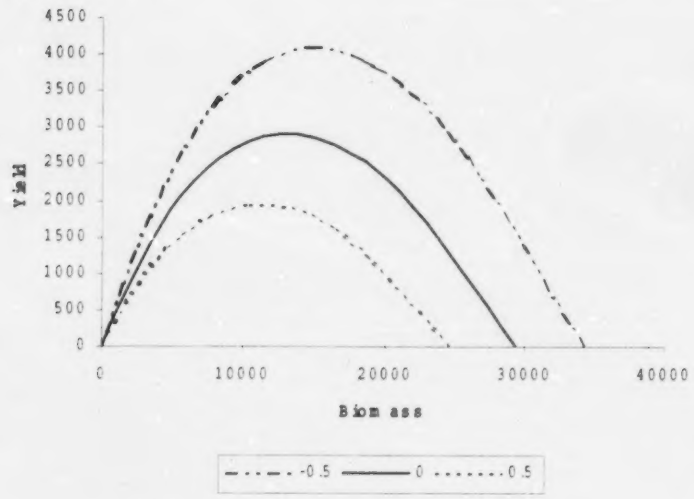


Figure 25: Trajectories of biomass and fishing mortality for area 5CD Pacific cod, estimated with delay difference models without (upper) and with (lower) sea level as a covariate. The vertical lines begin at B_{msy} and $0.5\,B_{msy}$ and terminate at F_{crash}. The horizontal line is at F_{msy} and terminates at B_0. The final 2 years (2000, 2001) are indicated by solid circles.



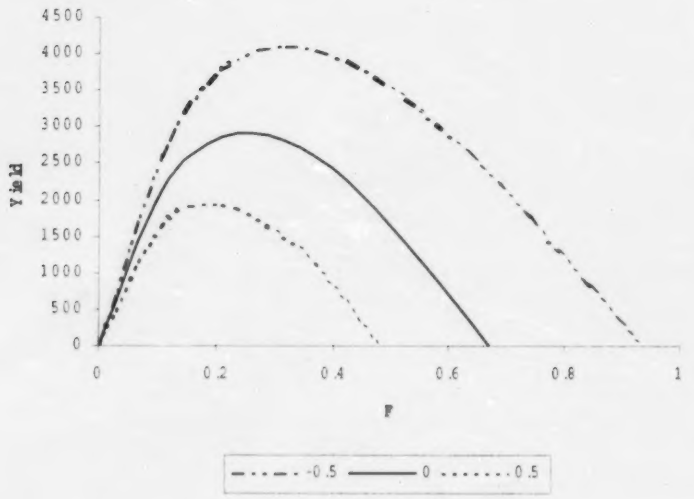


Figure 26: Predicted effects of variation in sea level height on production of area 5CD Pacific cod. Equilibrium yield curves are presented for +- 0.5 standard deviation of sea level height.

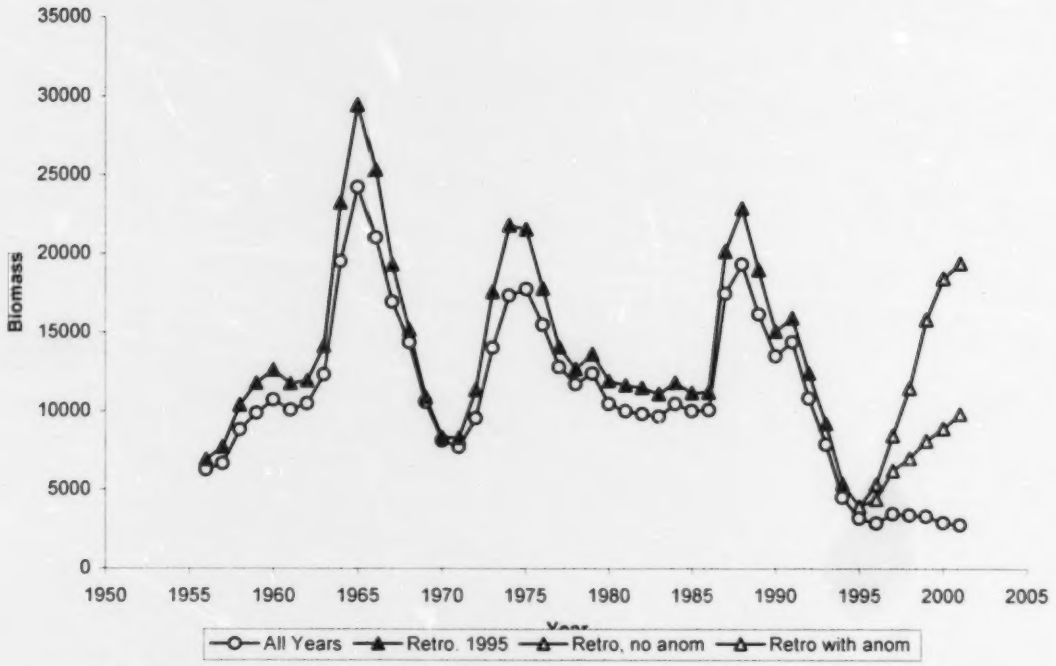


Figure 27: Comparison of biomass predictions for area 5CD Pacific cod made using all years data and a retrospective analysis using data up to 1995. The stock biomass was projected forward from 1995 in the retrospective analysis in 2 ways, one with no recruitment anomalies and the second using the estimated recruitment anomalies from the full analysis.

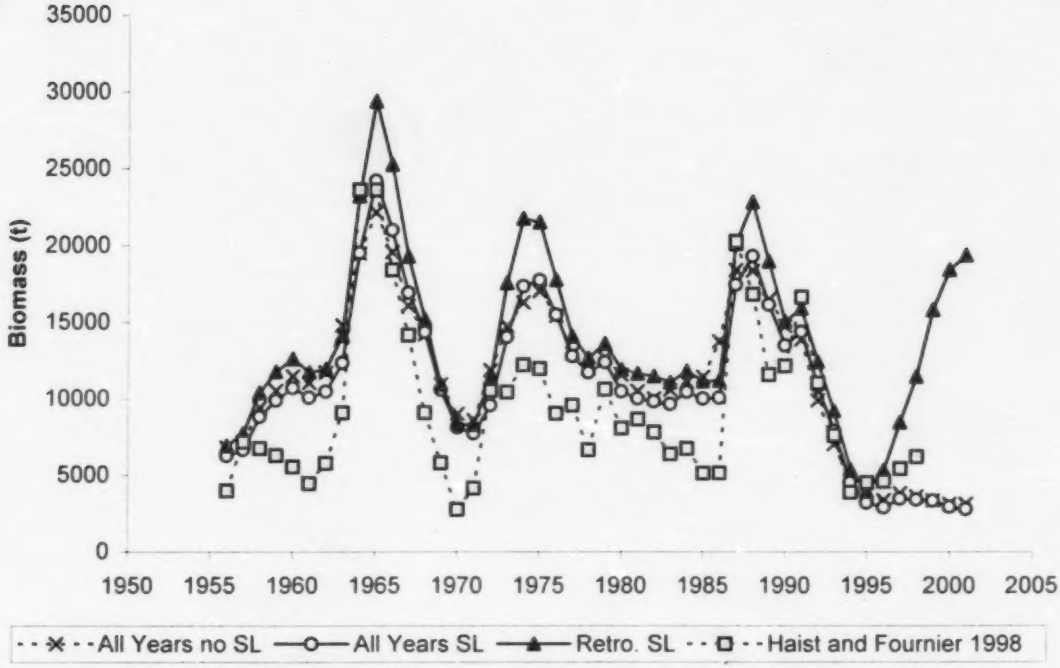


Figure 28: Comparison of biomass estimates for Pacific cod in area 5CD from 4 different models. These are delay difference production models using all years and no sea level, all years and sealevel, calibrated to 1995 and sea level, and a multifan catch at length analysis presented by Haist and Fournier 1998.

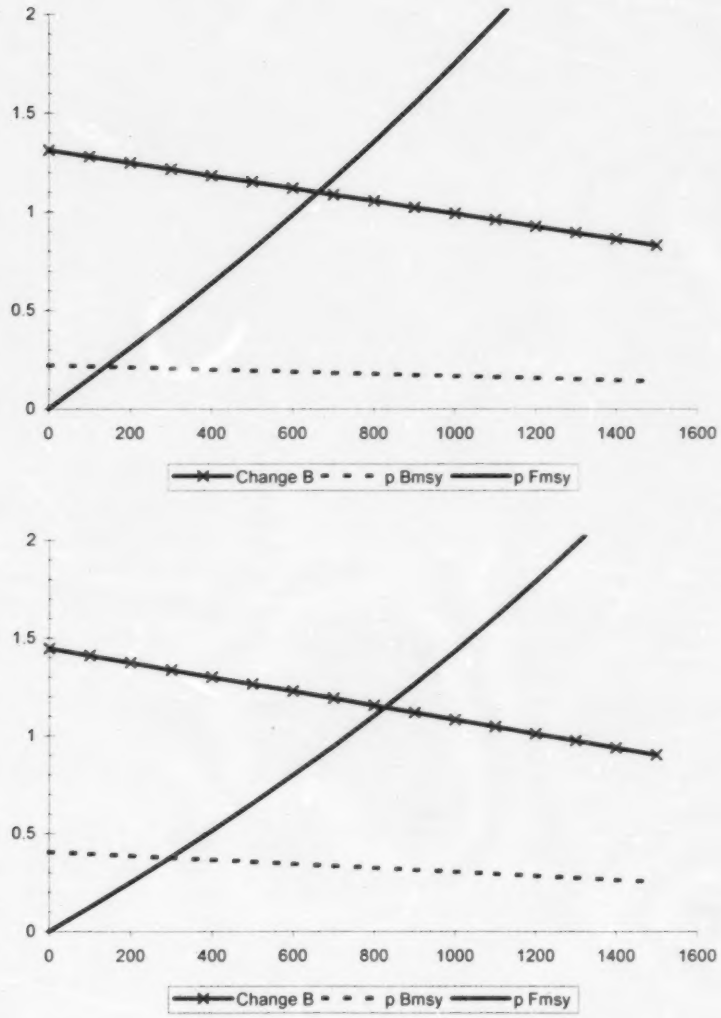


Figure 29: Summary of catch forecasts for area 5CD (Hecate Strait) Pacific cod from delay difference productions models without (upper) and with (Lower) sea level as a covariate. Three criteria are presented relative to the catch in 2002. The solid line with tick-marks gives the proportional change in stock biomass between 2002 and 2003. The dashed line indicates the proportion of F_{msy} that will result from the given catch. The solid line indicates the fraction of B_{msy} that will be present in 2003.

9. Appendix I: Request for Working Paper

Date Submitted: June 26, 2001

Individual or group requesting advice: Groundfish Management Unit

Proposed PSARC Presentation Date: November 2001

Subject of Paper (title if developed):

Hecate Strait and WCVI Pacific Cod Assessment and Recommended Yield Options or 2002

Stock Assessment Lead Author: Alan Sinclair

Fisheries Management Author/Reviewer: B. Ackerman

Rational for request:

A stock assessment was conducted in 2000 for Hecate Strait Pacific Cod that indicated a conservation concern for this stock. As a result, significant changes have been implemented in the 2000 management plan; including, spawning closures and quota reductions.

PSARC recommended that improvements to the stock assessment model, incorporating more of the stock dynamic of Pacific cod, be added to the 2001 Assessment.

No advice has been provided for WCVI stock and, in light of the conservation concerns for Hecate Strait, an assessment of WCVI stocks is warranted.

Question(s) to be addressed in the Working Paper:

1. What is the current biomass and stock size structure of Pacific Cod Hecate Strait and WCVI Pacific cod and how does this relate to historical stock conditions.
2. What is the expected trajectory of the HSS and WCVI Pacific cod to the end of 2002/2003 fishing season and how will this be affected by a range of annual TAC's.
3. What range of TAC's in Hecate Strait that would be consistent with PSARC direction for stock conservation and rebuilding.
4. What is an appropriate design for a monitoring program for Hecate Strait Pacific Cod given the reduced commercial fishing activity and the need to track stock status.

5. What were the impacts of the spawning closures for Hecate Strait in 2000 on catch compared to previous years.
6. Given conservation concerns in 2001, carryforward/overage provisions were revoked for the 2001 fishing plan. Is carryforward/overage provisions appropriate for Pacific Cod and how would this affect yield advice for 2002?

Objective of Working Paper: *(StAD staff to develop further jointly with management)*

6. To review surveys, biological, sampling, catch records, logbooks, observer reports, and fishing practices for Pacific Cod to provide a basis for management for the 2002/2003 fishery in Hecate Strait and WCVI.
7. To provide an assessment of Hecate Strait and WCVI pacific cod stock status.
8. To provide stock projections based on various yield options.
9. To recommend appropriate yield options.
10. To recommend a stock monitoring program for Hecate Stratic pacific cod.

StAD staff may want to take above questions and develop more explicit objectives these are a mix of general and specific objectives.